Appendix A: Climate impacts and adaptation actions for wolverine

Figure A.1. Wolverine.

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the wolverine (*Gulo gulo*).

The wolverine is a highly mobile and wide-ranging carnivore.[2] Wolverines have a strong preference for landscapes with deep and persistent snowpack, and avoid human developments in their home ranges and during dispersal.[2,3] Wolverine can travel long distances and will move through a wide range of habitat types during dispersal.[2] In the transboundary region of Washington and British Columbia, the wolverine's primary alpine and subalpine habitat exhibits relatively high connectivity within the Cascade Range, but is fragmented regionally by both human factors (e.g., highways, towns) and natural factors (e.g., low elevation river valleys). Significant barriers to movement are presented by major highways, the Okanagan Valley, and the Fraser River Valley (Appendix A.1).[2]

Future climate change may present additional challenges and needs for wolverine habitat connectivity.[4-5] First, climate change may impact wolverine core habitat and dispersal corridors in ways that may make them more or less permeable to movement. Second, existing wolverine core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in wolverine distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[6] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for wolverine habitat connectivity in the transboundary region (but see McKelvey et al. (2011)[7]). To address these needs, we describe here a novel effort to identify and address potential climate impacts on wolverine habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary wolverine habitat connectivity, project participants created a conceptual model that identifies the key landscape features and processes expected to influence wolverine habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix A.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models

[i] This report is Appendix A of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[8] The wolverine conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to wolverine habitat connectivity.

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on wolverine habitat connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,9] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[10] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[12]

Key impacts on transboundary wolverine habitat connectivity identified via this approach include changes in areas of wolverine climatic suitability, changes in vegetation, declines in the amount and duration of snowpack, changes in the accessibility of wolverine habitat for recreation and other land uses.

Changes in areas of climatic suitability

Climate change may impact wolverine habitat connectivity by changing the extent and location of areas of climatic suitability for wolverine; this may render some existing core habitat areas and corridors unsuitable for wolverines, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climatic suitability, and are available for the wolverine for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1(T47) and UKMO-HadCM3[ii]) under the A2 (high) carbon emissions scenario[iii] (Appendix A.3).

Results from the UKMO-HadCM3 model project that extensive areas of current wolverine range become climatically unsuitable by the 2080s. In the southern Coast Range, climatically suitable areas remain in the high elevations, and mountain peaks that were previously excluded from the wolverine's range are projected to become climatically suitable. While suitability generally declines east of the Okanagan Valley, some small, fragmented areas at higher elevations persist. All habitat areas within the Rockies and the North Cascades are projected to become climatically unsuitable. Assuming that the wolverine is

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[ii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

constrained by climate conditions currently found within their range, the UKMO-HadCM3 projections suggest a dramatic range contraction throughout the transboundary area.

In contrast, the CGCM3.1(T47) projections suggest a lesser degree of change. Most of the North Cascades and Coast Range remain climatically suitable, and many high elevation peaks become suitable. However, most of suitable habitat in the Rockies is projected to become unsuitable, with the exception of the highest peaks. The contrast between these two climate models suggest that projected changes to the wolverine's climatic niche are highly sensitive to uncertainties around how the climate may change.

Changes in vegetation

Wolverines prefer habitat above treeline during the summer. Changes in treeline in the transboundary region could therefore be expected to affect wolverine habitat connectivity.

Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models (Appendix G.4).[iv] Both types of models are based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[ii] Both models also use the A2 (high) emissions scenario.[iii] Both mechanistic and climatic niche vegetation models project that cold forest vegetation types will shift higher in elevation and replace open alpine habitat (Appendix A.4). Projected upward shifts in treeline would lead to smaller, more isolated areas of wolverine core habitat.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack (Appendix A.6: Spring (April 1st) Snowpack; Length of Snow Season) may affect the quality of wolverine core habitat areas and corridors. Deep, persistent spring snowpack is critical for successful wolverine denning and reproduction. Consequently, projected future declines in spring snowpack are likely to result in fewer, smaller, and more isolated patches of wolverine core habitat.[7] Loss of snowpack could also negatively affect wolverine dispersal among remaining core habitat areas; Schwartz et al. (2009)[3] estimate that wolverine movement costs over snow covered landscapes are 1/20th that of movement costs across landscapes without snow. Consequently, declines in the amount and duration of snowpack could impede wolverine dispersal, further isolating remaining populations.[7] Declines in the amount and duration of snowpack may also lead to earlier opening of roads and increased opportunities for road development at higher elevation locations. Resulting increases in road access at high elevation locations could negatively impact wolverine core habitat and connectivity.

Changes in the timing, location, and intensity of recreation

Because wolverines avoid areas used by people, climate-driven shifts in the locations and/or intensities of activities such as heli-skiing, snowmobiling and/or summer recreation activities may have a negative impact on wolverine habitat and connectivity.

[iv] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

Changes in disturbance regimes

Climate change may affect wolverine habitat connectivity by increasing severity of summer drought (Appendix A.6: Water Deficit, July – September), increasing the risk of wildfires (Appendix A.6: Days with High Fire Risk), and influencing pest and pathogen dynamics (Appendix A.5). At endemic levels, mountain pine beetles help create snags and fallen logs that wolverines use for denning sites. In Washington state, probability of mountain pine beetle survival is projected to decline at lower elevations, but to increase at high elevations (Appendix I.5). While summer drought (Appendix A.5: Water Deficit, July-September) and risk of wildfires may also help create snags and coarse woody debris used as denning sites, extreme drought and large, high-intensity fires may negatively affect forest habitats used by wolverine.

Adaptation responses

After identifying potential climate impacts on wolverine habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix A.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on wolverine habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in wolverine distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on wolverine habitat connectivity

Actions to address projected upward shifts in treeline include:

- Monitoring changes in treeline using LIDAR remote sensing, to improve capacity for identifying and responding to changes in wolverine core habitat areas.

Actions to address projected decrease in the depth and persistence of snowpack include:

- Increasing snow depth locally (e.g., by installing snow fences), with the caveat that given the large home range sizes of wolverines, local-scale snow management is unlikely to have a significant impact on wolverine core habitat quality. Therefore, consider prioritizing such efforts within important habitat areas (e.g., near known denning sites) and corridors.
- Identifying areas where deep spring snowpack is most likely to persist in the future (Appendix A.6), such as north-facing slopes and topographically shaded areas. Consider directing snowpack retention efforts to these areas, and prioritizing them when managing for wolverine core habitat and corridors.
- Managing roads to minimize impacts if declines in snowpack result in earlier access to wolverine core habitat areas and corridors, particularly during the denning season. Proposals to develop new roads at higher elevations should be carefully evaluated to determine impacts on wolverine habitat connectivity.

Actions to address changes in the timing, location, and intensity of backcountry recreational activities (e.g., skiing or snowmobiling) include:

- Monitoring recreation levels within wolverine core habitat areas and corridors to identify and address changes that may negatively affect habitat connectivity. Minimize recreation in wolverine core habitat areas during sensitive times (e.g., during the denning period).

Actions to address the potential for climate change to impact wolverine habitat connectivity through more frequent and severe wildfires and pest outbreaks include:

- Using prescribed burns and thinning to reduce the risk of catastrophic wildfires and pest outbreaks that could negatively impact wolverine core habitat areas and corridors.

Enhancing connectivity to facilitate range shifts

Actions that may help wolverine adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors between areas of declining climatic suitability for wolverine and areas of stability or increasing suitability (Appendix A.1 and Appendix A.3).[7]
- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors,[9] Appendix A.1), to ensure that wolverines have the ability to disperse into cooler, higher elevation habitats as the climate warms.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Corridors that provide east-west connectivity between the Coast Range and the Rocky Mountains. The Coast Range, with projected increases in climatic suitability at high elevations, would likely provide the closest suitable habitat to the Rocky Mountains, where suitability is projected to decline.
- Corridors that provide connectivity between the Coast Range and the Cascade Range, where suitability is projected to decline.
- The Fraser River Canyon, which may currently pose a significant barrier to connectivity between the Coast Range and the Cascade Range.
- The Okanagan Valley, which presents a major barrier to movement and falls within a corridor linking the Rockies to the Cascade Range.
- Highways, especially those with high traffic volumes where they cross wolverine core habitat areas and corridors. For example, Highway 3 cuts east-west through E.C. Manning Provincial Park in British Columbia and may create a dispersal barrier for south-north movement through the North Cascades; if there is evidence that the road creates a barrier, it could be a candidate for a crossing.
- Climate-gradient corridors, which may help wolverines disperse into cooler habitats as climate warms.

Policy considerations

Land use planning and management

Actions for addressing climate impacts on wolverine habitat connectivity through land use planning and management:

- Coordinating with protected areas managers to minimize recreation impacts on wolverine habitat connectivity.

- Coordinating with land managers to evaluate appropriate responses to potential changes in seasonal road openings and closings within high value wolverine habitat as snow conditions change.
- In British Columbia, encouraging forestry companies to comply with forestry requirements for areas important to wolverine (particularly within climate resilient core habitat areas): retain refugia, plan forest development, minimize road access, maintain known seasonal forage areas, protect known den sites, and minimize recreation.
- Reviewing and implementing existing guidance and plans relating to wolverine habitat management. Evaluate existing recommendations for opportunities to address climate impacts.
- Investigating whether having multiple priority species affected in the same area can lead to greater pressure to change management practices if cumulative impacts can be demonstrated.

Transportation planning

Actions for addressing climate impacts on wolverine connectivity through transportation planning include:

- Coordinating with transportation agencies to evaluate appropriate management responses to potential changes in seasonal road openings and closings within wolverine core habitat areas as snow conditions change.
- Coordinating with transportation agencies to ensure that new roads do not negatively impact climate-gradient corridors, or climate-resilient wolverine core habitat and corridors (see Additional Research, below). When new roads are inevitable, mitigate barrier effects by incorporating crossing structures into road design.

Research Needs

Future research that could help inform wolverine habitat connectivity conservation under climate change include:

- Identifying potential climate impacts on specific wolverine core habitat areas and corridors. Overlay projected changes in climate with existing wolverine corridor maps to quantify expected impacts on specific areas within the network. This may help direct adaptation actions to appropriate areas.
- Identifying climate resilient wolverine habitat cores and corridors. Overlay corridor networks (Appendix A.1) with climatic niche models (Appendix A.3), and projected changes in vegetation (Appendix A.4) and snow cover (Appendix A.6); core areas and corridors within the current range that are projected by multiple models to retain suitable climatic conditions and vegetation may be most likely to be resilient. Climate-resilient core habitat areas and corridors may be used to identify priority areas for the adaptation actions described above.
- Identifying corridors between locations with projected declines in climatic suitability and areas with projected stable or improving climatic suitability. Use climatic niche models (Appendix A.3), vegetation projections (Appendix A.4), and projected changes in snow cover (Appendix A.6) to identify these locations. Use corridor models (Appendix A.1) to identify potential corridors for connecting vulnerable wolverine core habitat areas to areas projected to remain climatically suitable or become newly suitable.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[v]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[vi] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

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[v] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[vi] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices A.1-5

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For wolverine, these materials include:

Appendix A.1. Habitat connectivity models
Appendix A.2. Conceptual model of habitat connectivity
Appendix A.3. Climatic niche models
Appendix A.4. Projected changes in vegetation communities
Appendix A.5. Projected changes in probability of mountain pine beetle survival
Appendix A.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,9] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[10] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[12]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig A.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

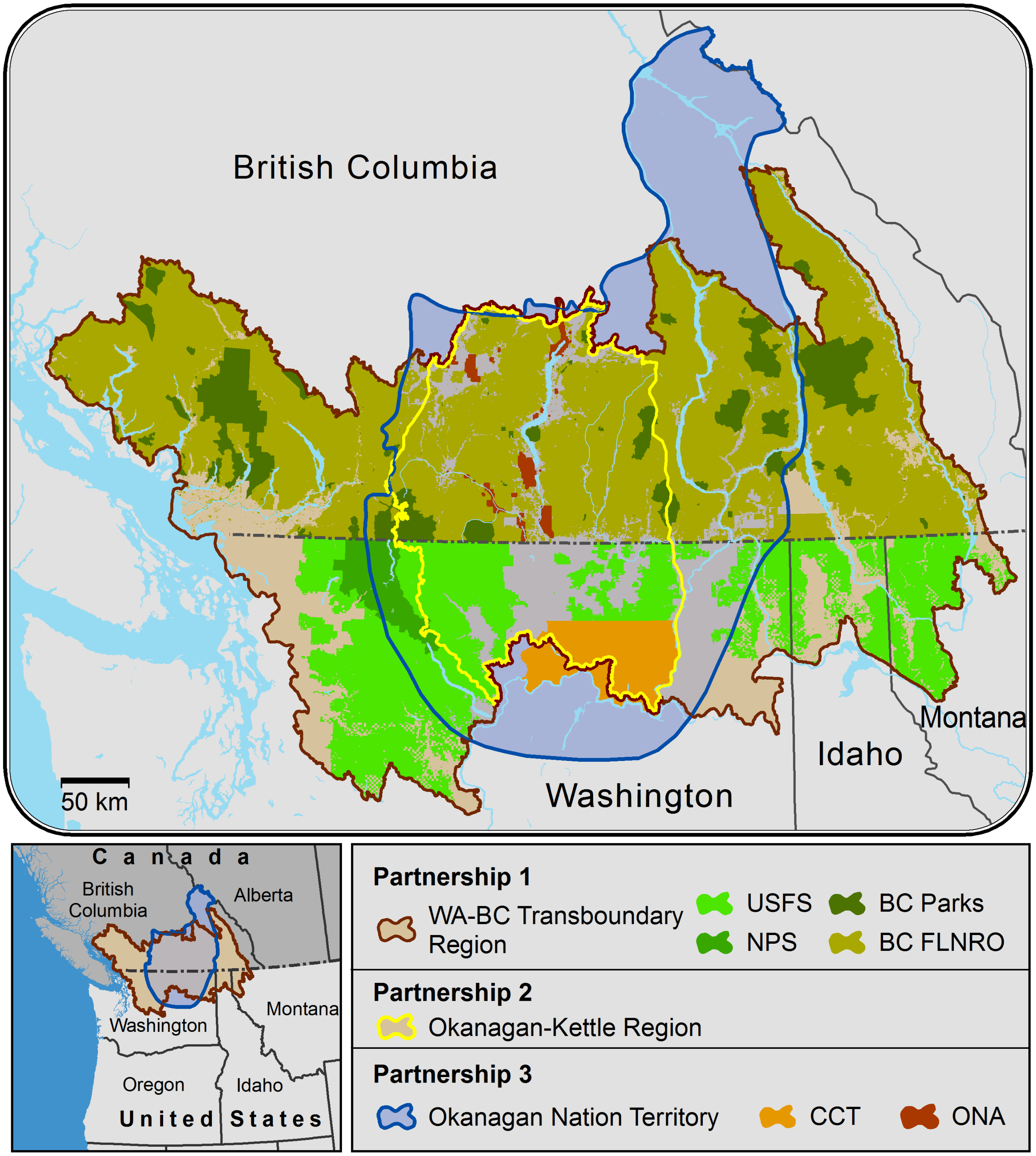


Figure A.2. Project partners and assessment areas.

Appendix A.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vii] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

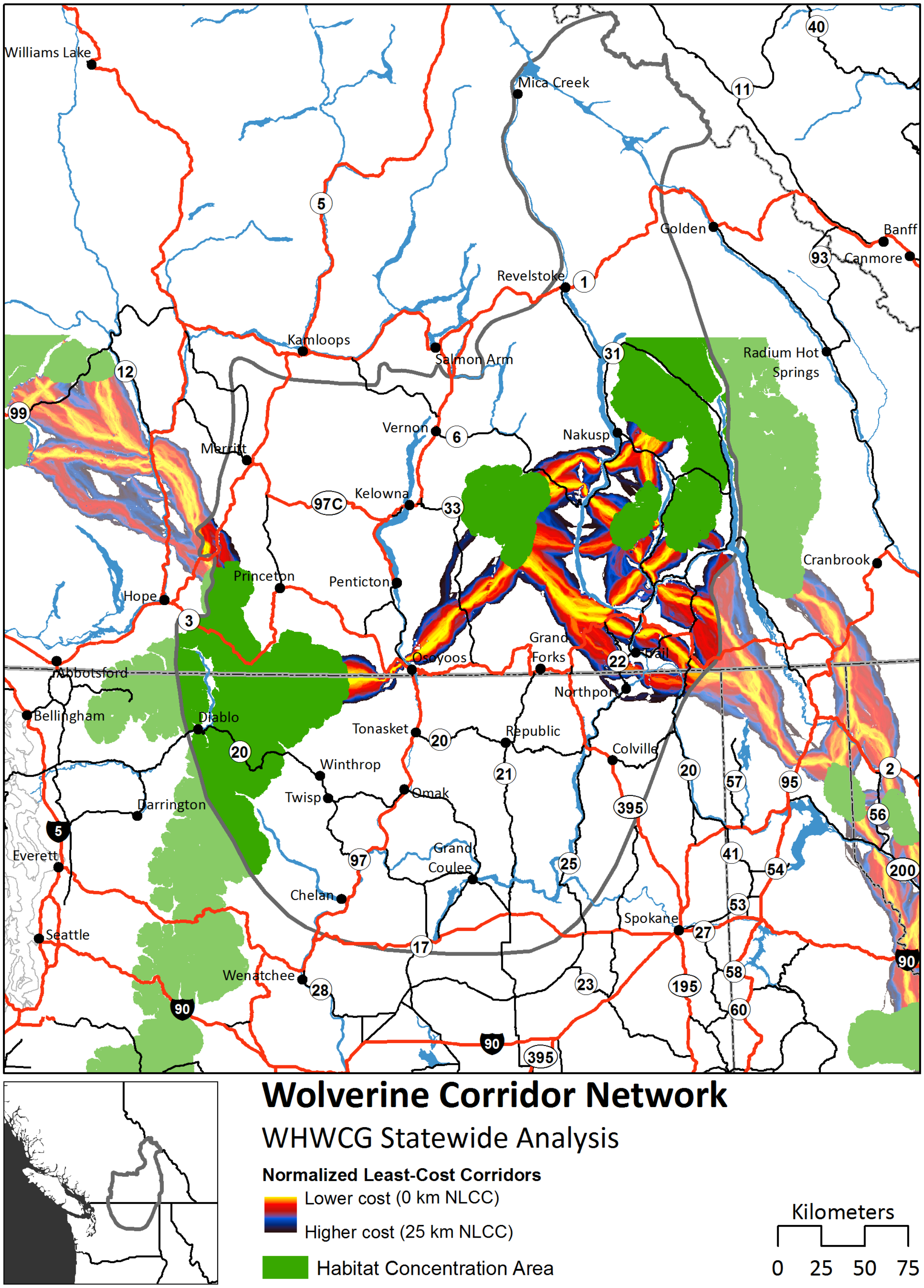
a) **WHCWG Statewide Analysis: Wolverine Corridor Network.[2]** This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).[9]** This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vii] For detailed methodology and data layers see http://www.waconnected.org.

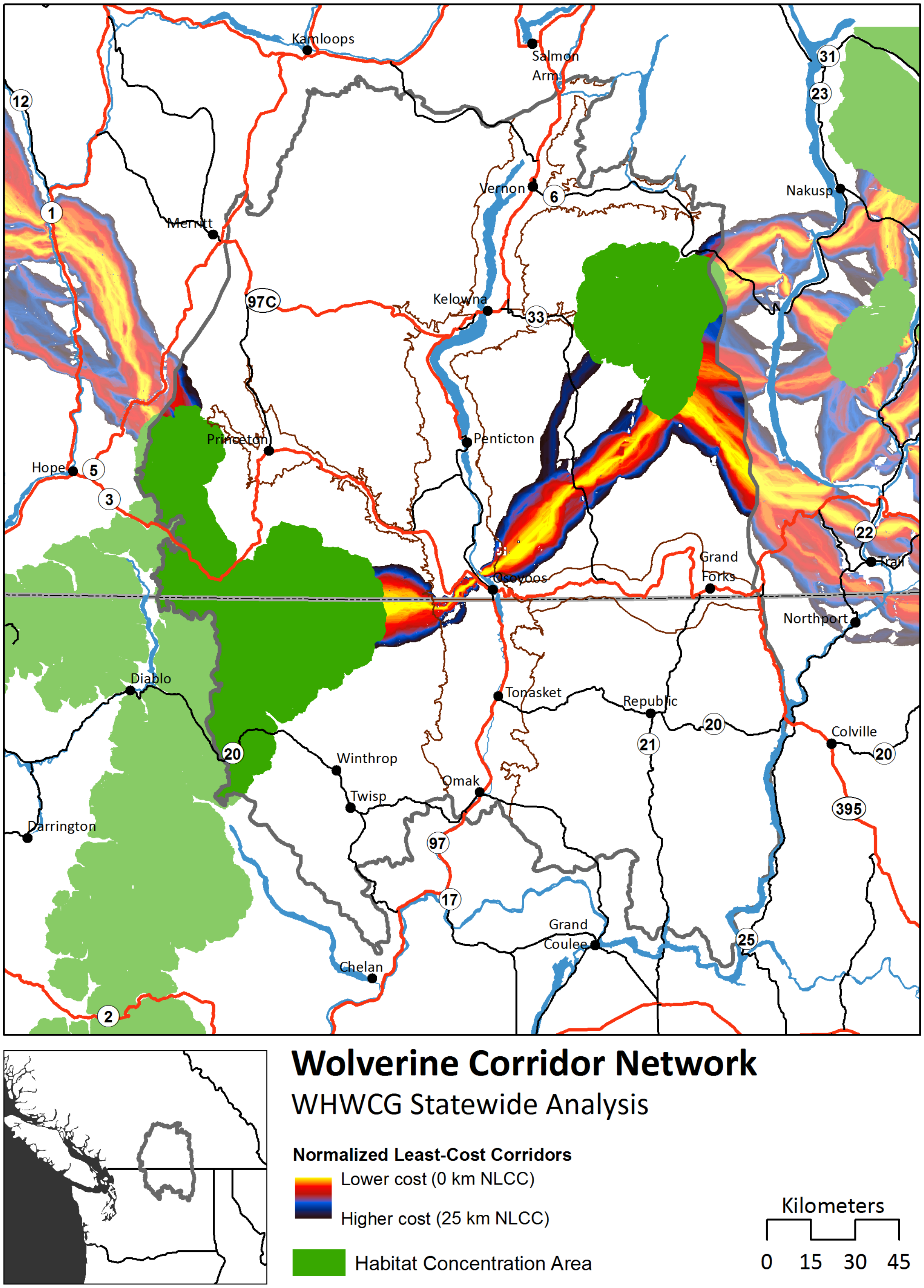
Appendix A.1a. WHCWG Statewide Analysis: Wolverine Corridor Model

i) Extent: Okanagan Nation Territory



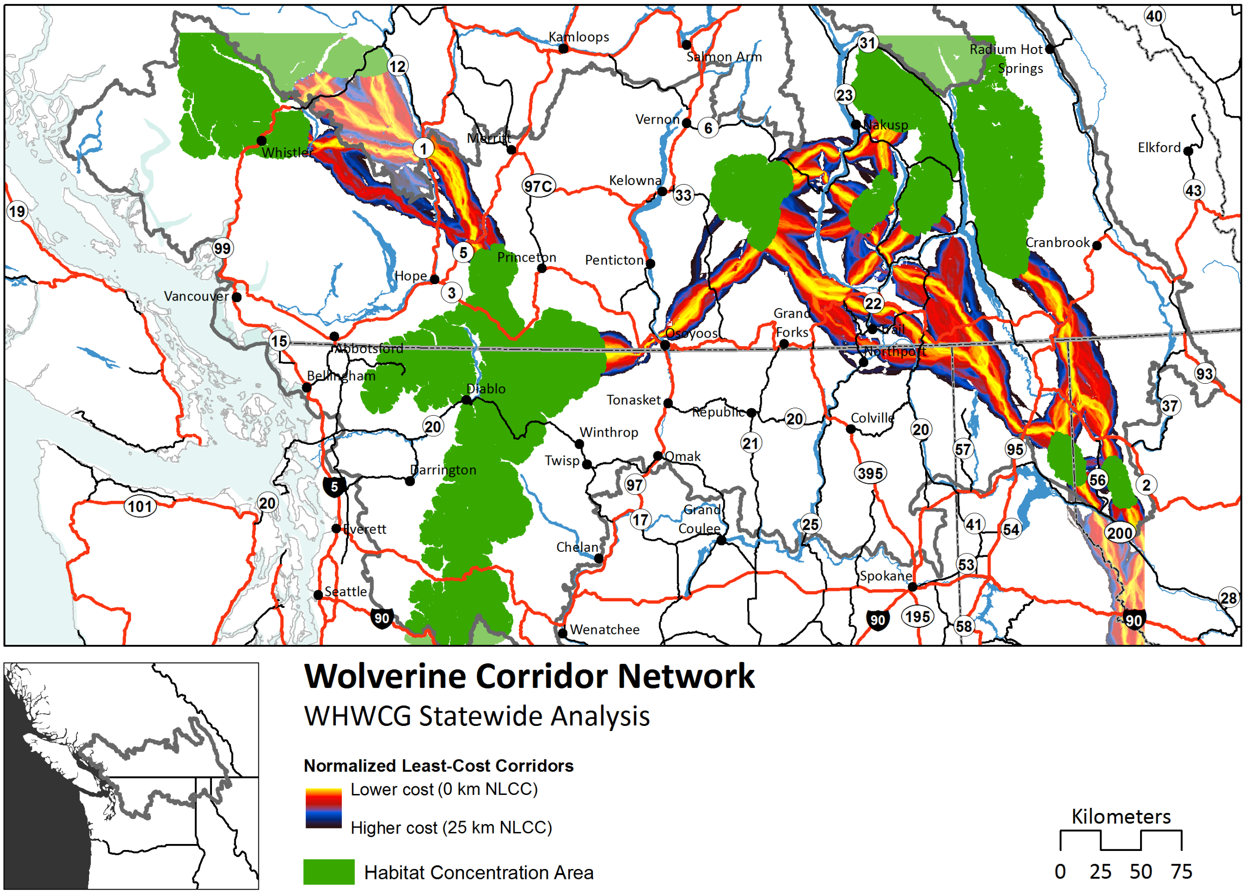
Appendix A.1a. WHCWG Statewide Analysis: Wolverine Corridor Model

ii) Extent: Okanagan-Kettle Region



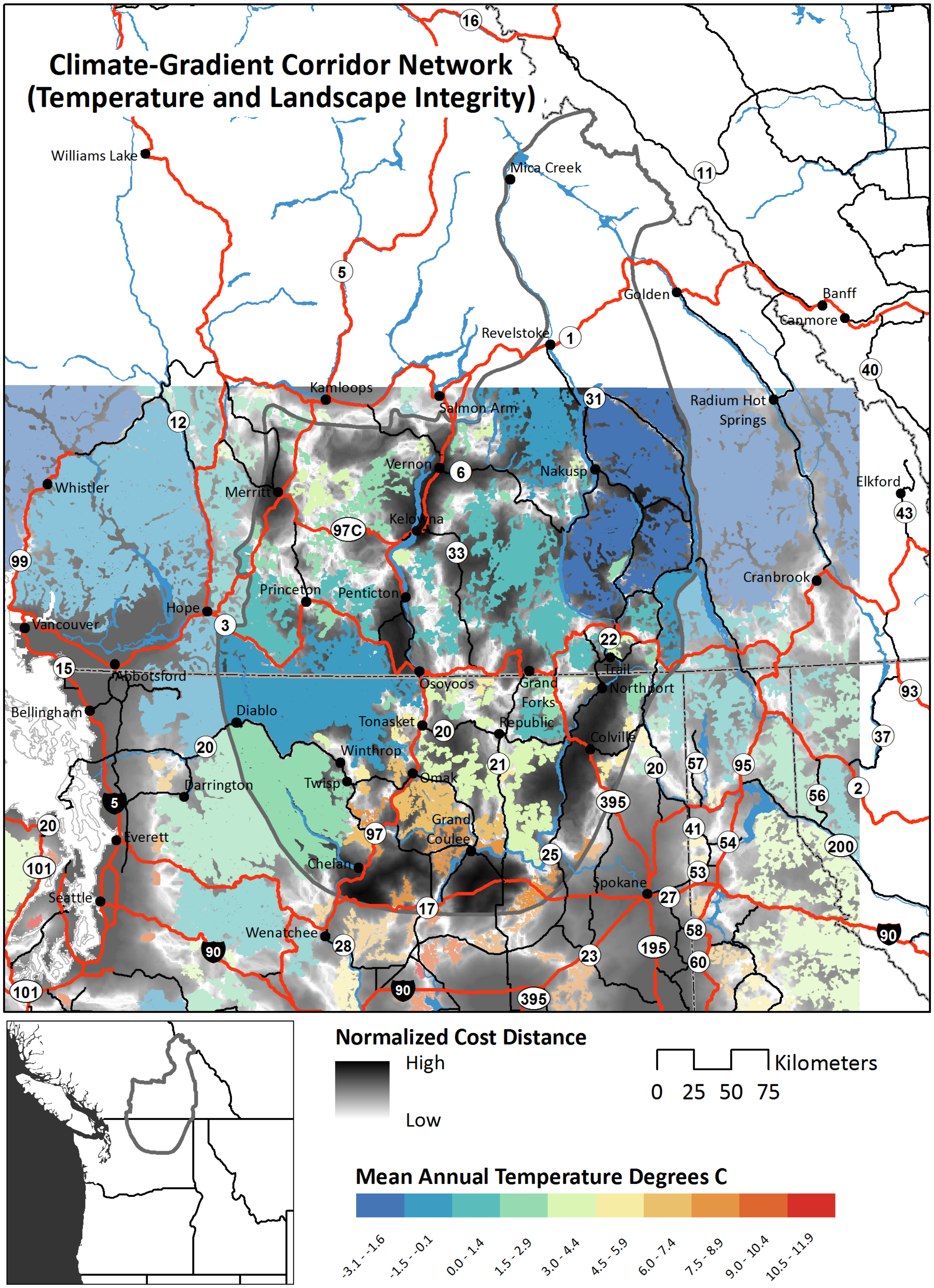
Appendix A.1a. WHCWG Statewide Analysis: Wolverine Corridor Model

iii) Extent: Washington-British Columbia Transboundary Region



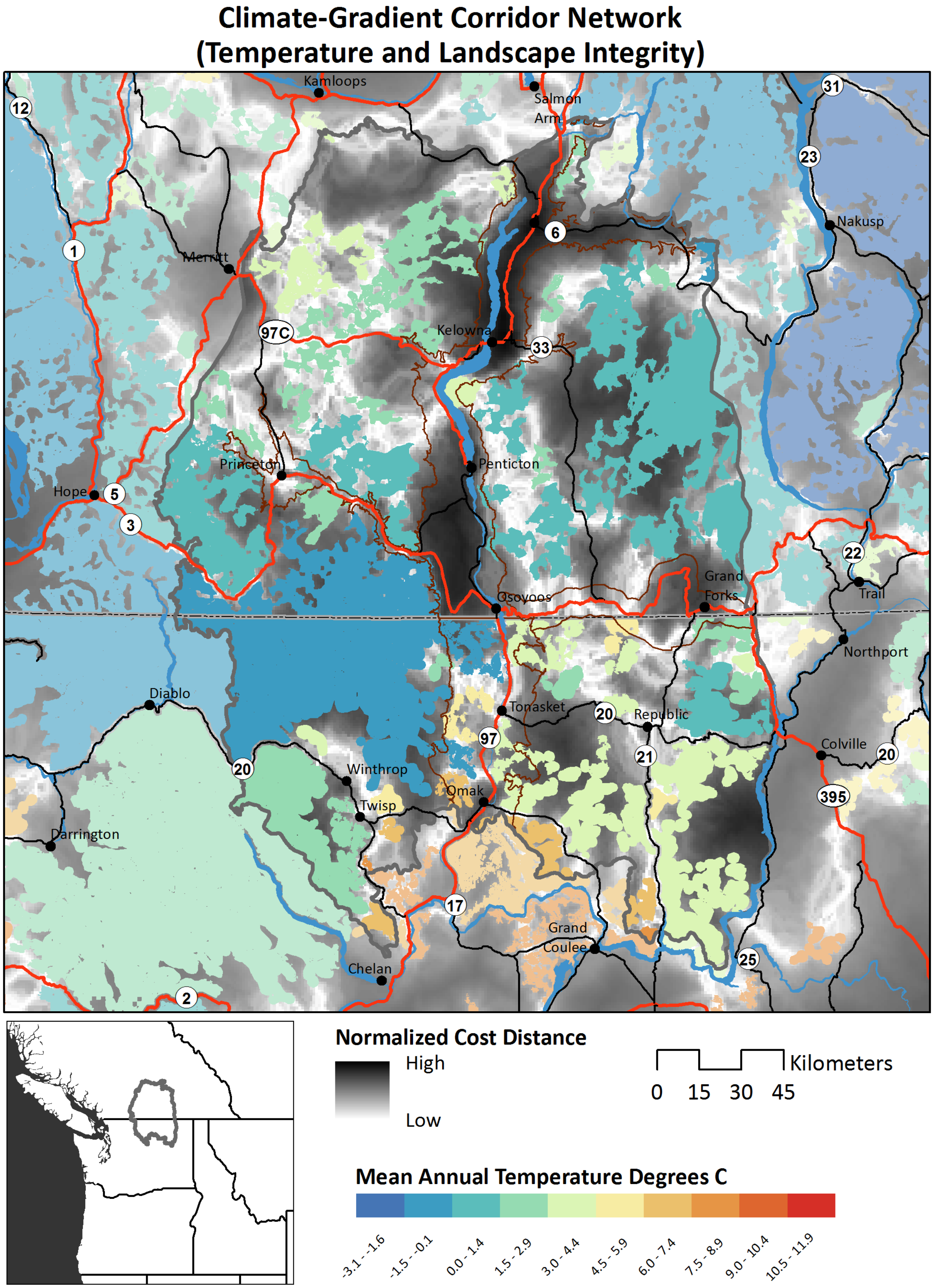
Appendix A.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory



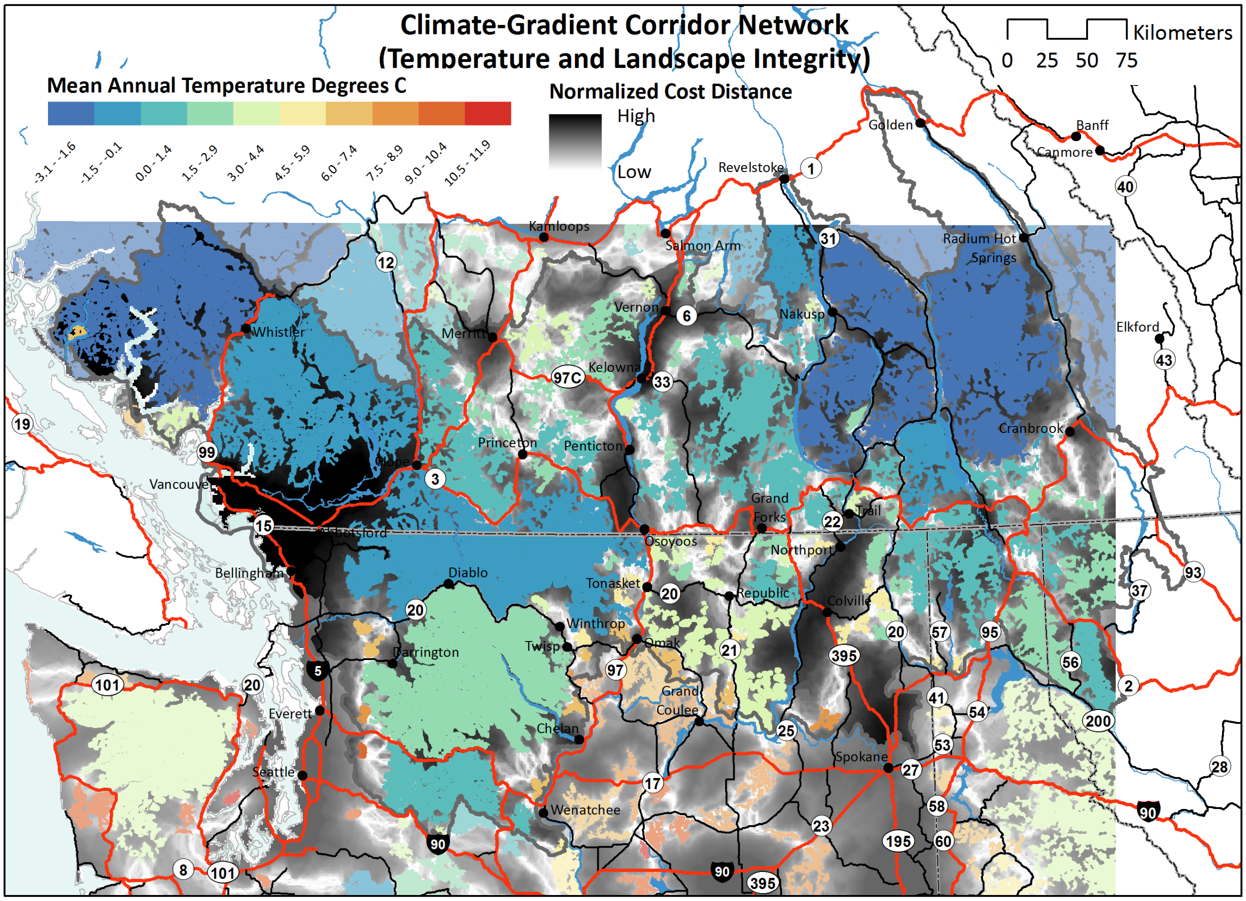
Appendix A.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region



Appendix A.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix A.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary wolverine habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence wolverine habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[8] The wolverine conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to wolverine habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the wolverine conceptual model included:

- Cliff Nietvelt, BC FLNRO
- Rich Weir, Environment Canada
- Kevin McKelvey, USFS Rocky Mountain Research Station

Key references used to create the wolverine conceptual model included:

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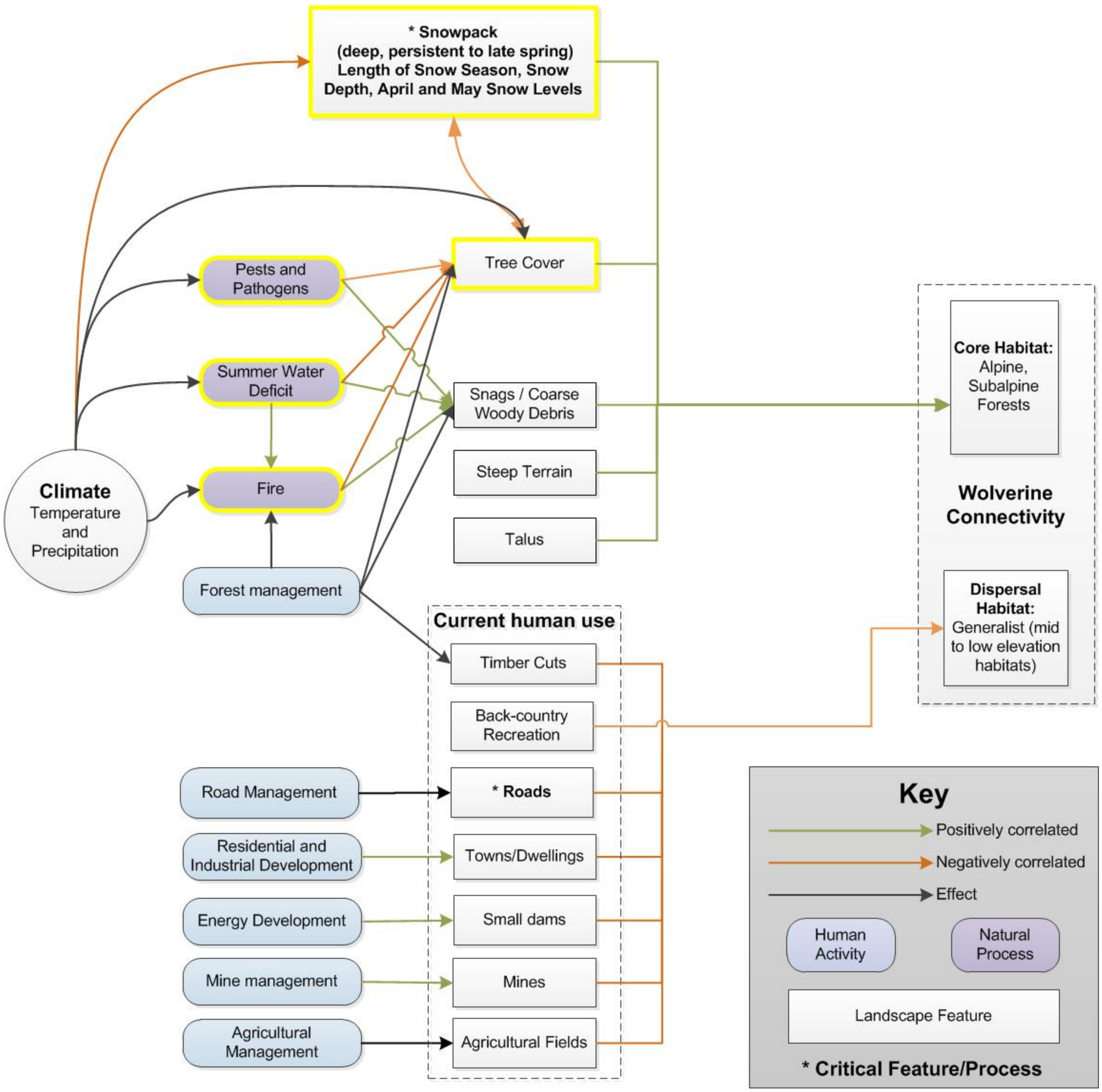
Appendix A.2. Conceptual Model of Wolverine Habitat Connectivity



Appendix A.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[viii] Both models use the A2 (high) emissions scenario.[ix] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[x]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

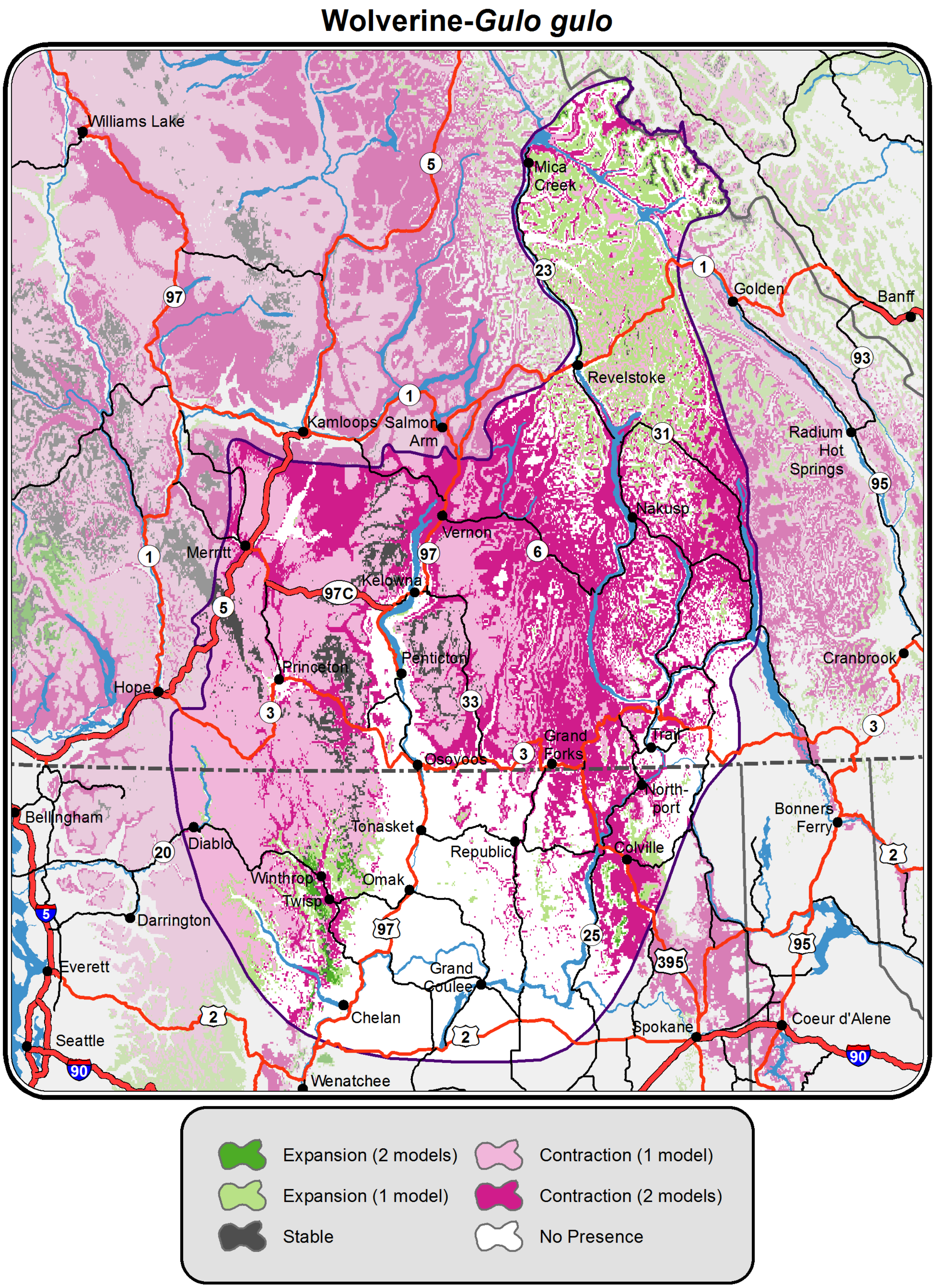
[viii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[ix] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[x] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix A.3. Wolverine Climatic Niche Model

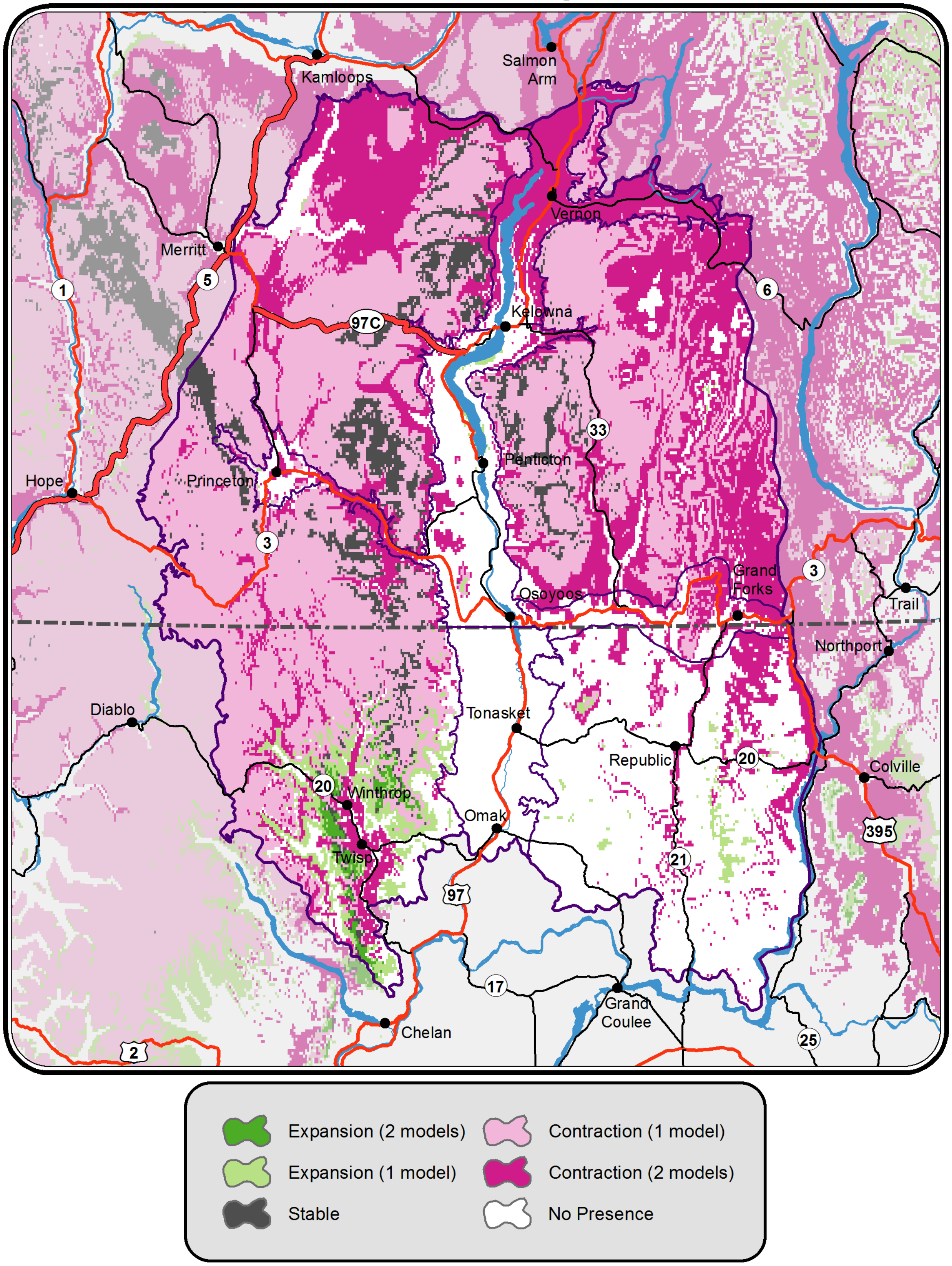
i) Extent: Okanagan Nation Territory



Appendix A.3. Wolverine Climatic Niche Model

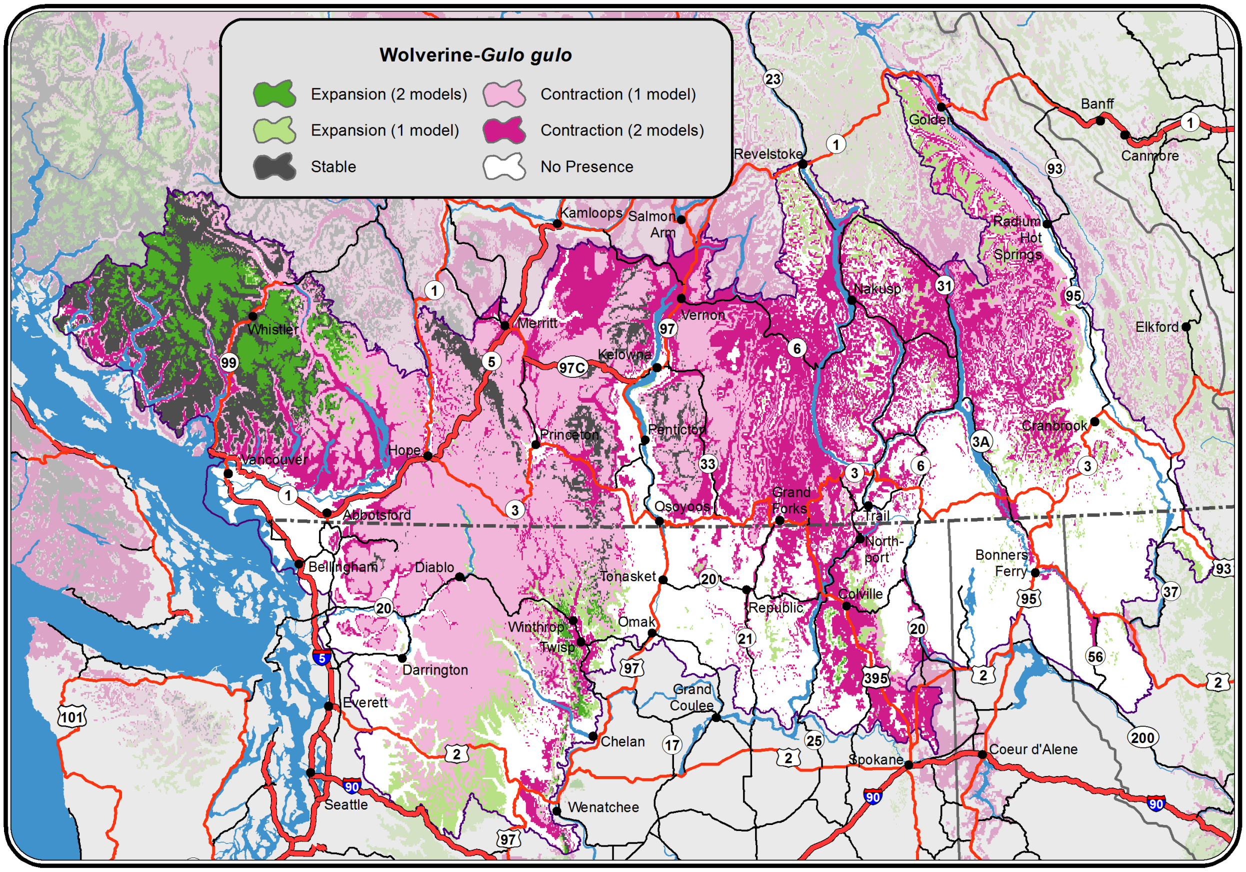
ii) Extent: Okanagan-Kettle Region

Wolverine-*Gulo gulo*



Appendix A.3. Wolverine Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix A.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xi] Both models also use the A2 (high) emissions scenario.[xii]

a) **Biome Climatic Niche Vegetation Model.**[xiii] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xiv] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[xi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

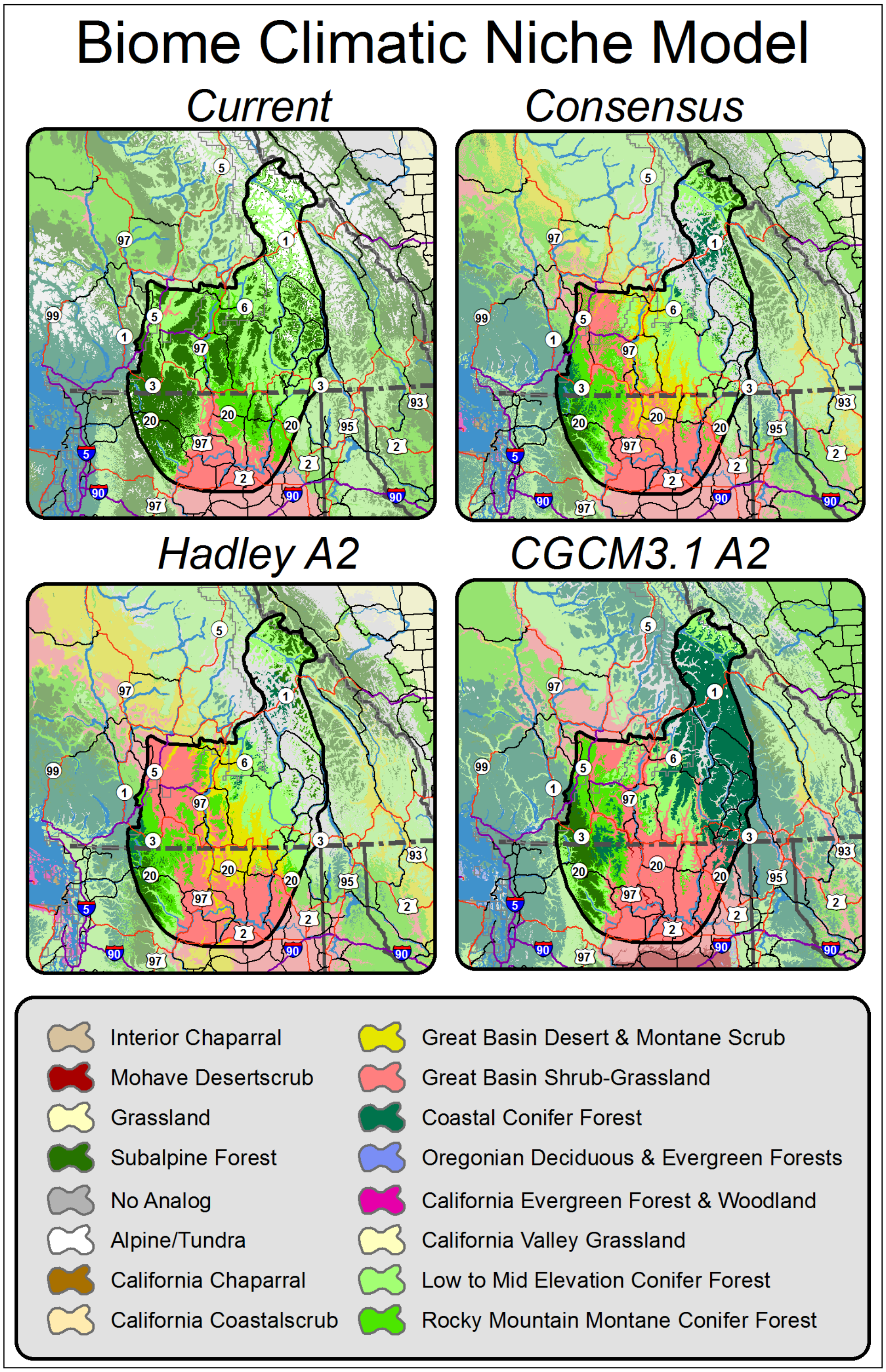
[xii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xiii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiv] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

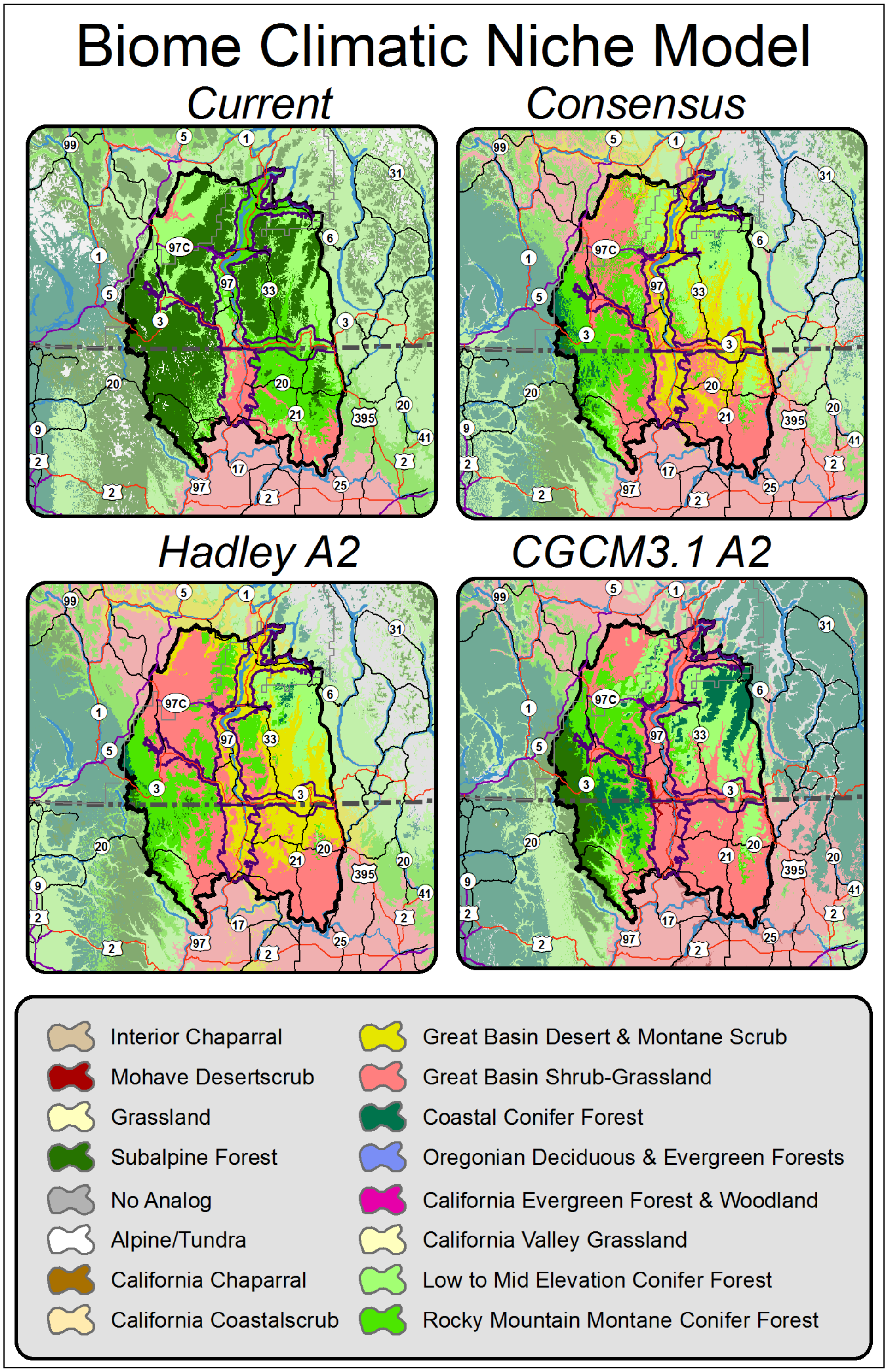
Appendix A.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



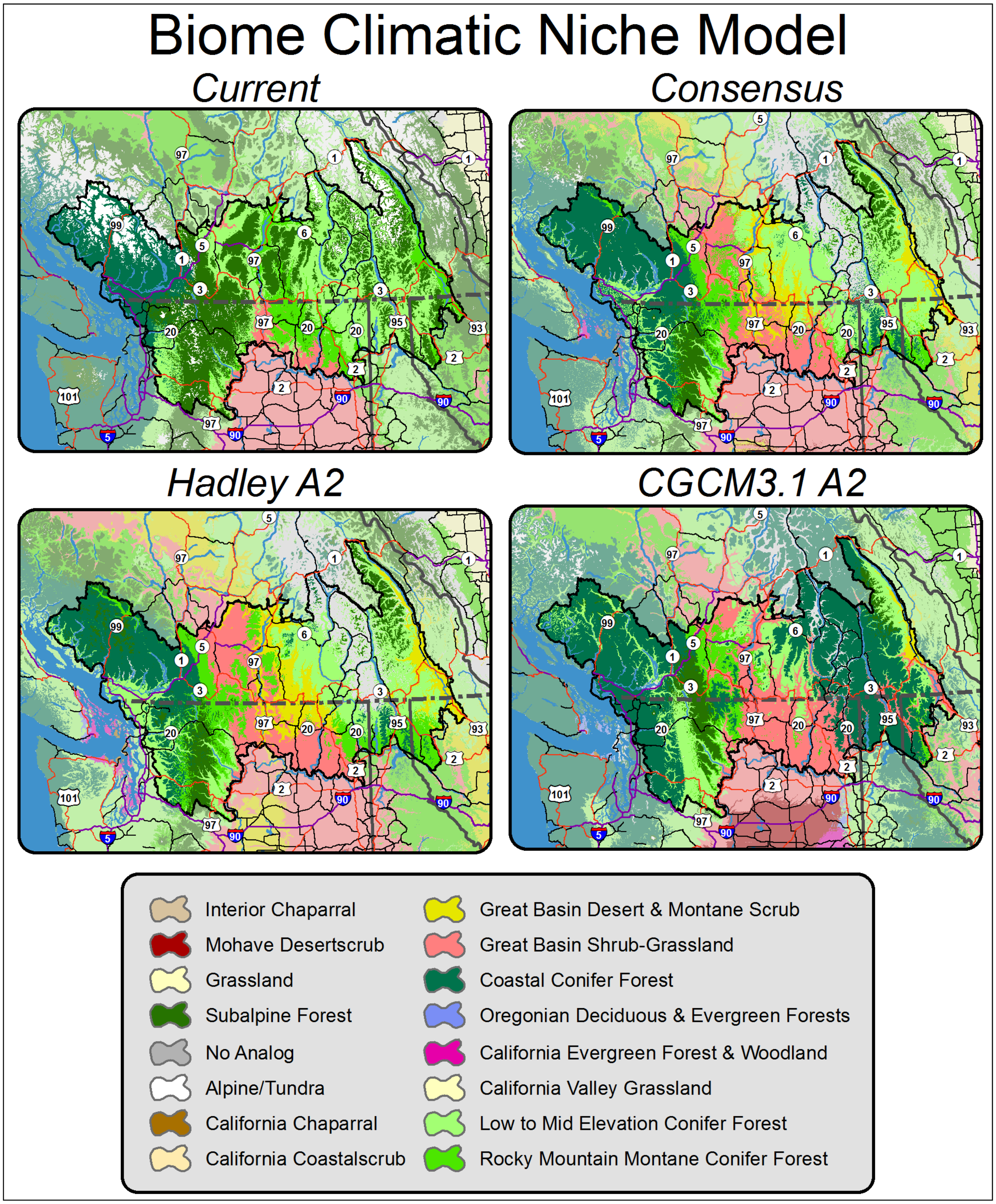
Appendix A.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



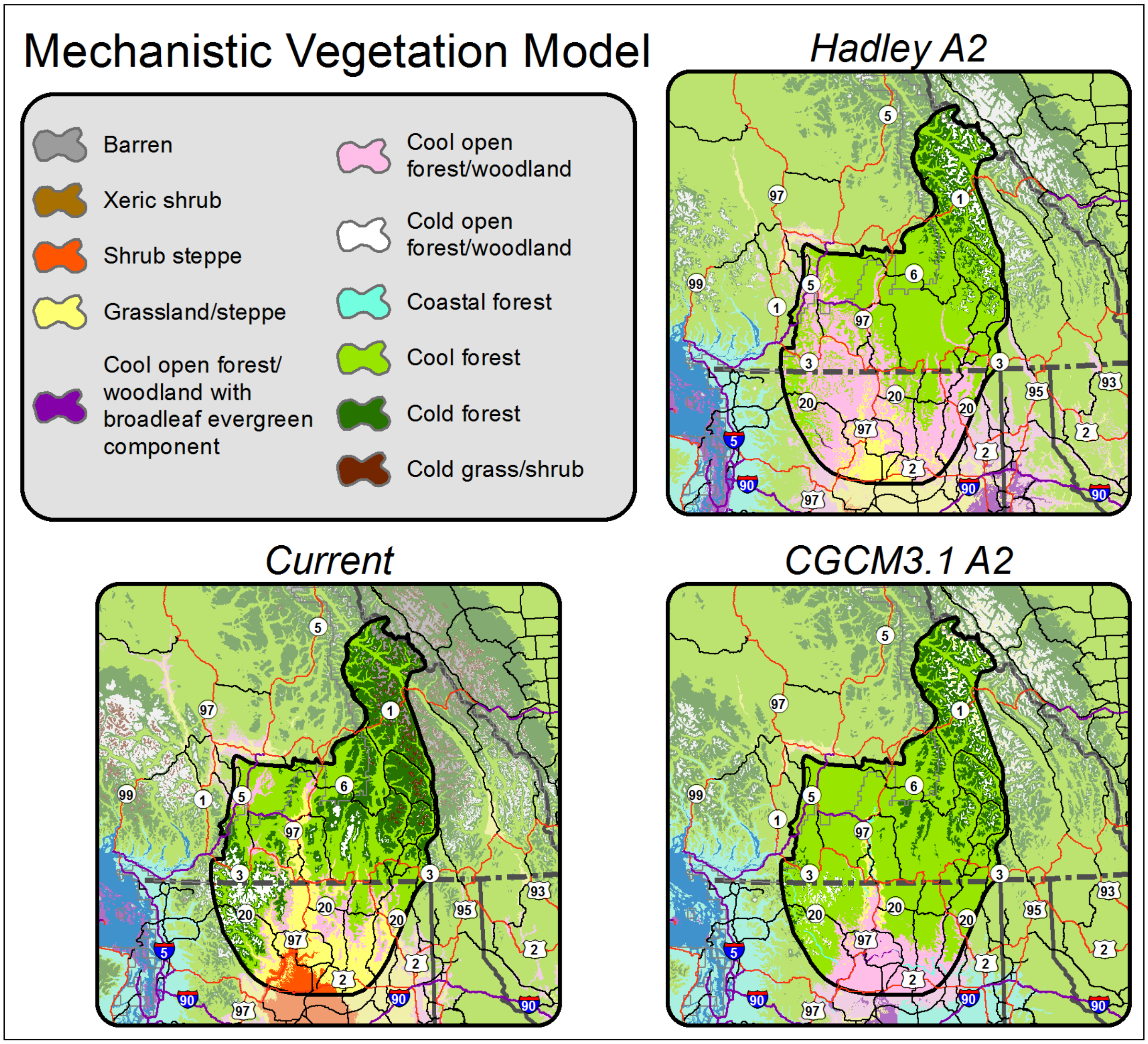
Appendix A.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



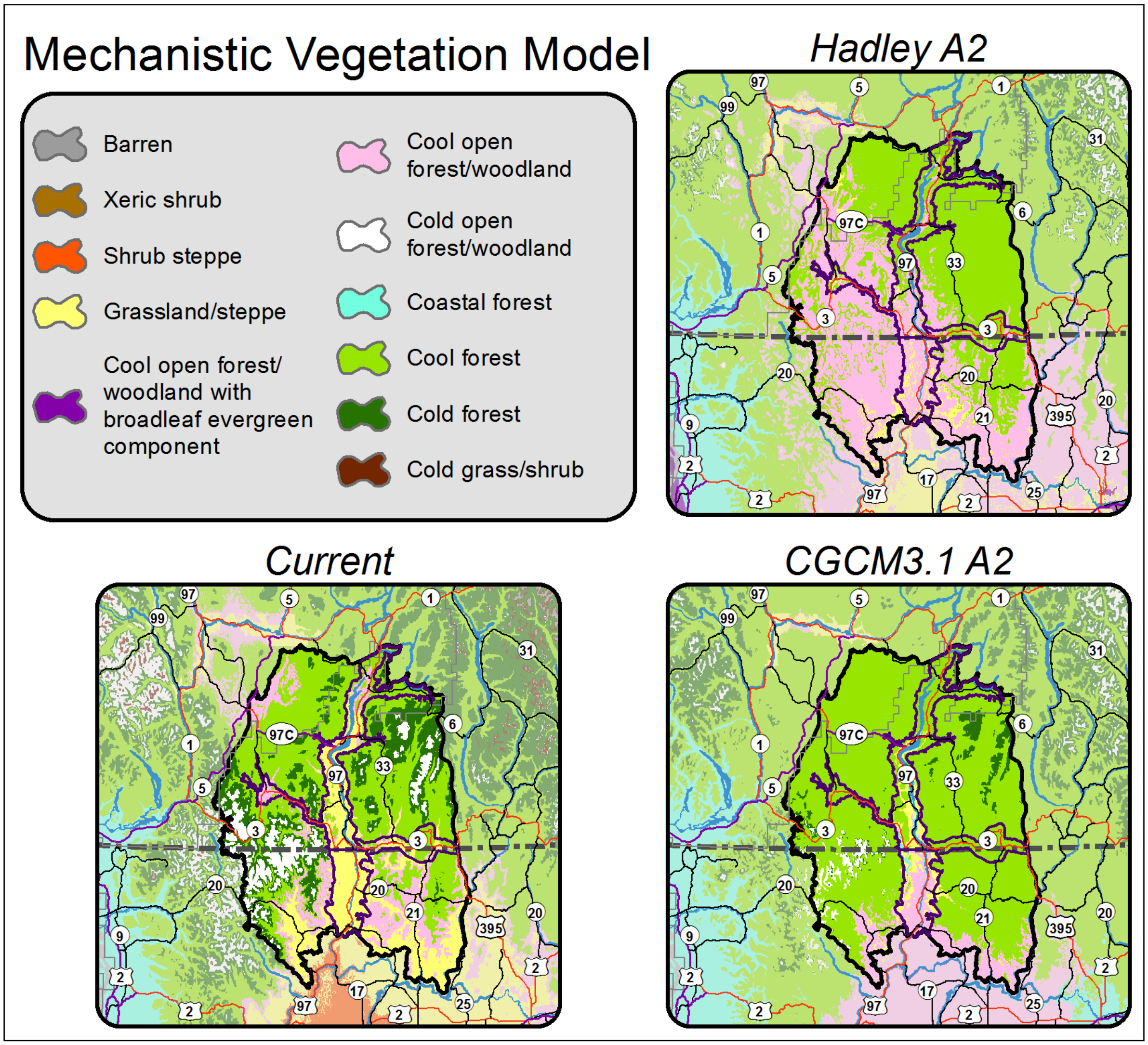
Appendix A.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



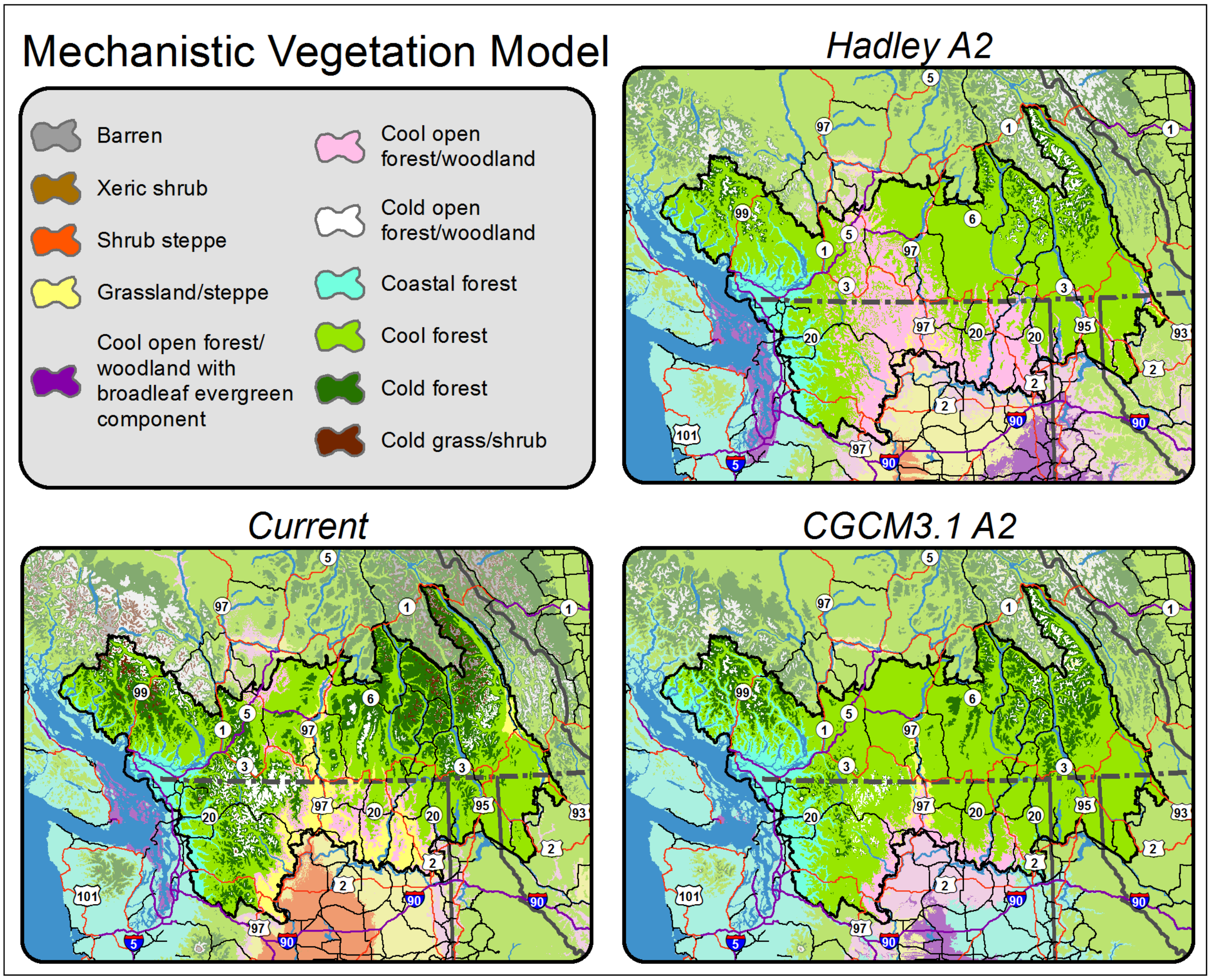
Appendix A.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix A.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



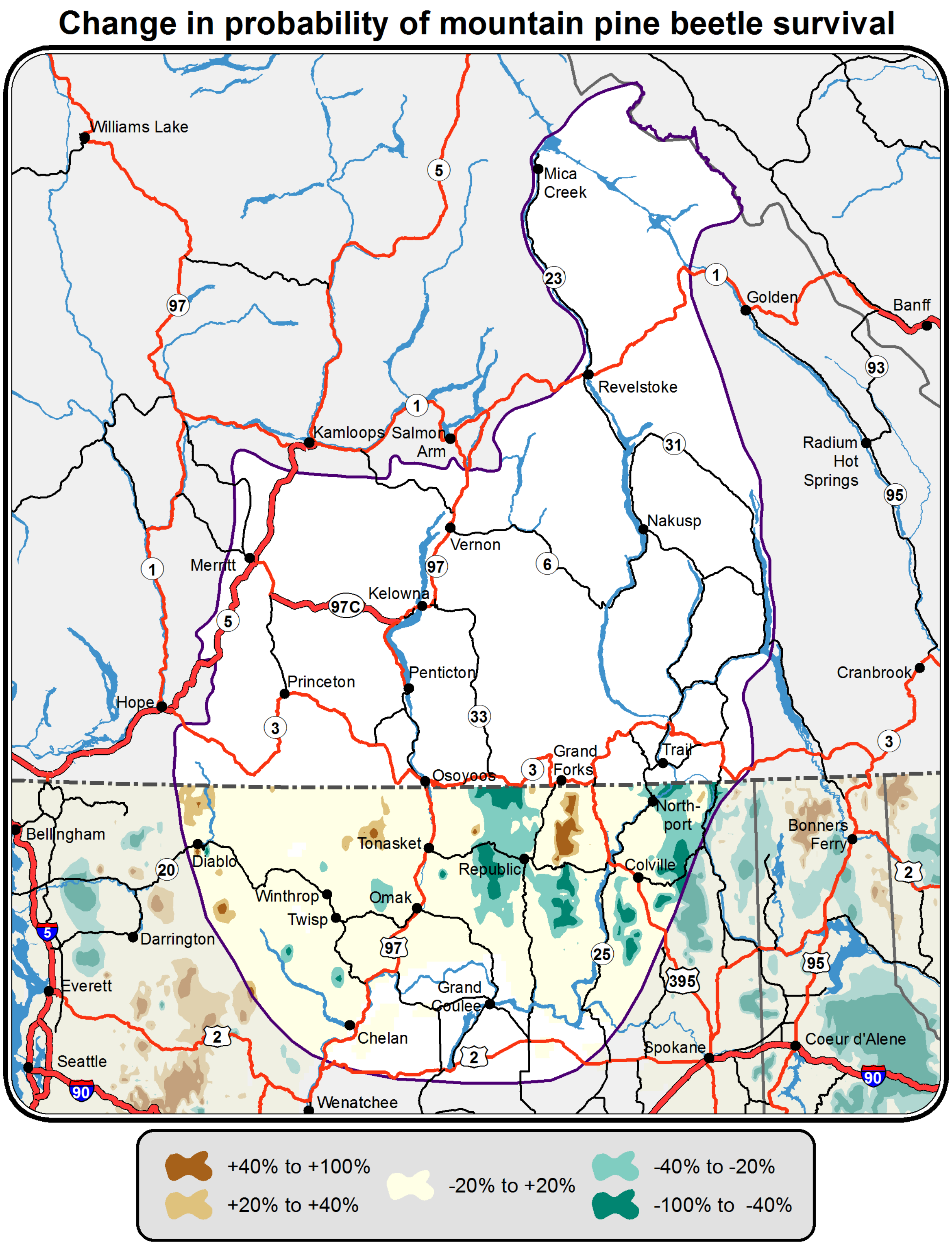
Appendix H.5. Projected Changes in Probability of Mountain Pine Beetle Survival

Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xv,xvi]

[xv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.
[xvi] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation.[xv] Projections are only available for the United States.

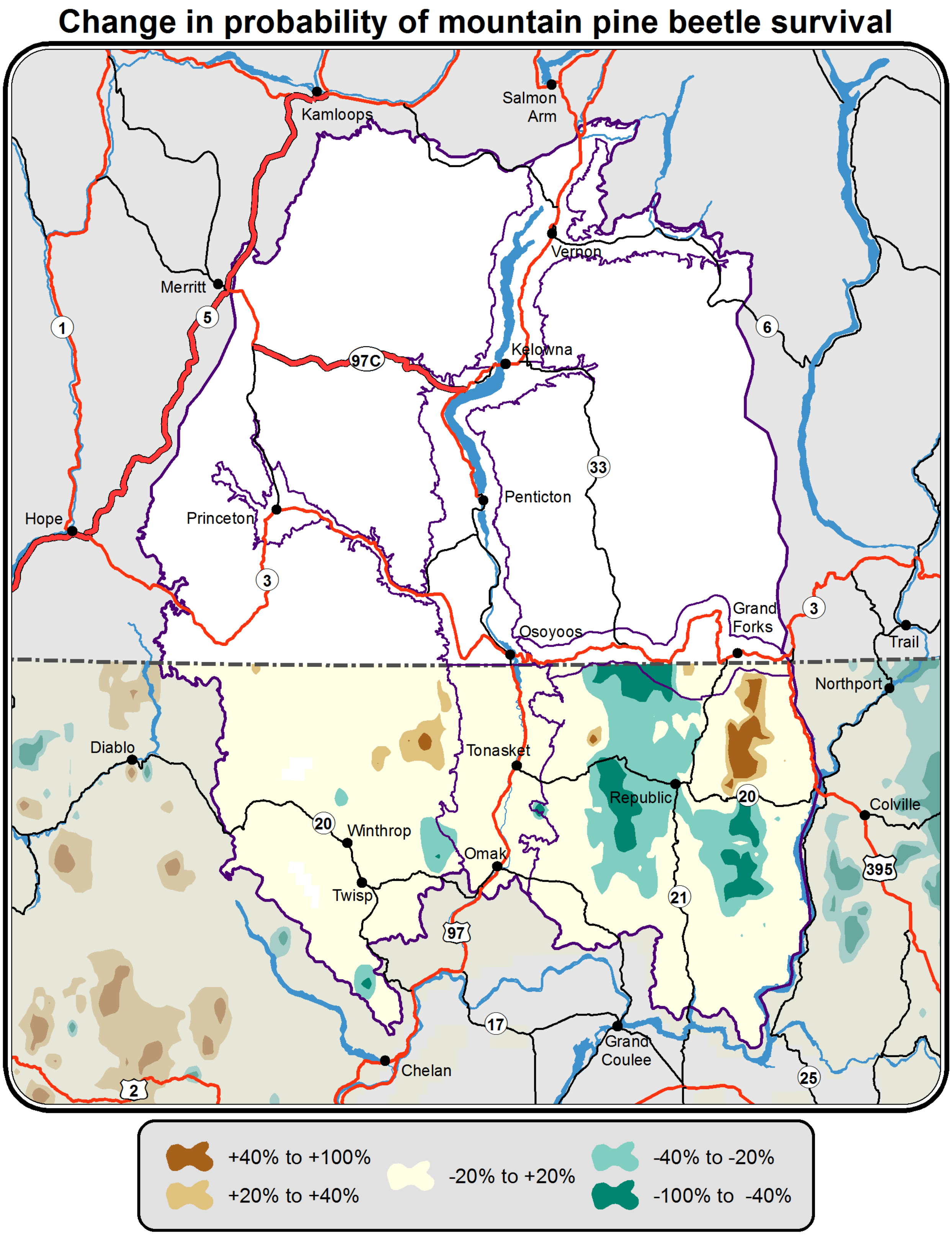
Appendix H.5. Probability of Mountain Pine Beetle Survival

i) Extent: Okanagan Nation Territory



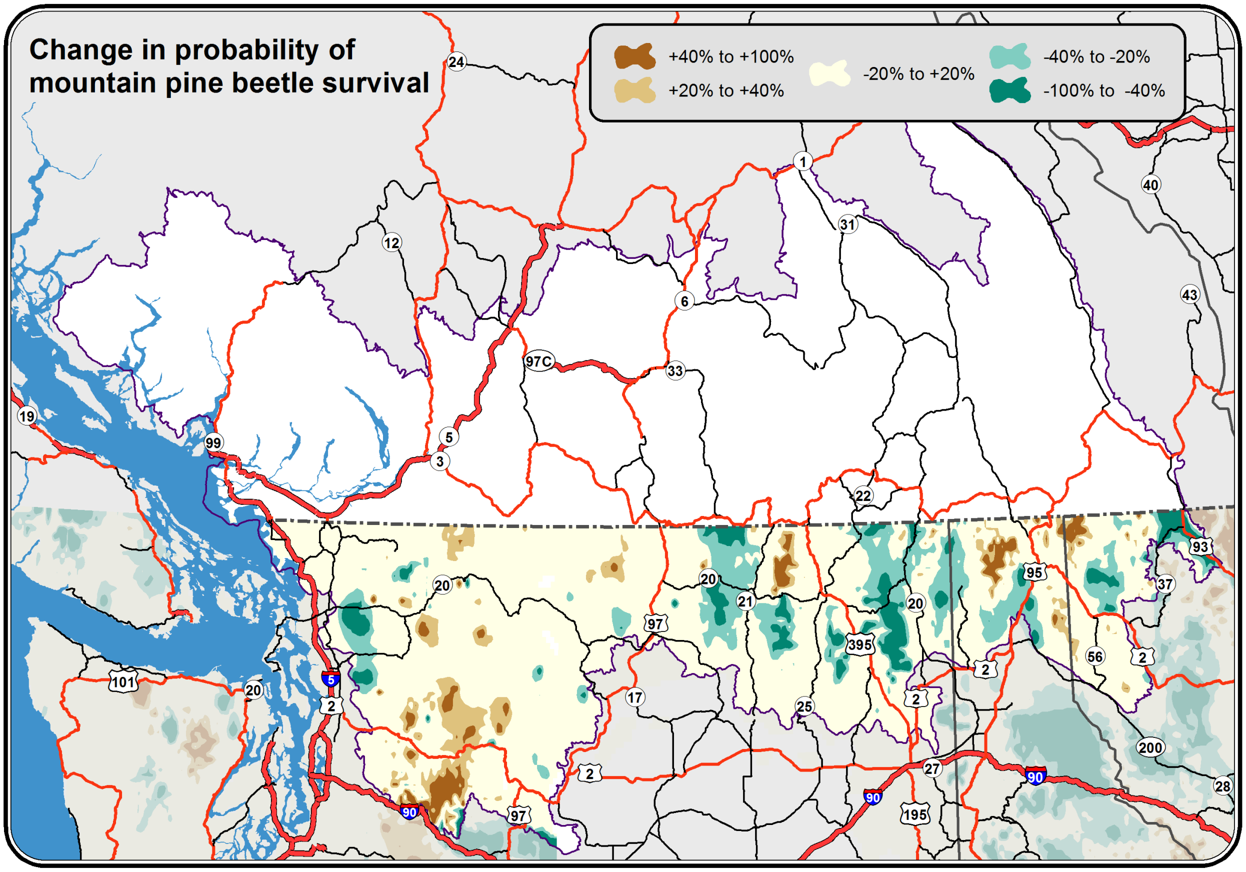
Appendix H.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region



Appendix H.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region



Appendix A.6. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on wolverine connectivity.[xvii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[10] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

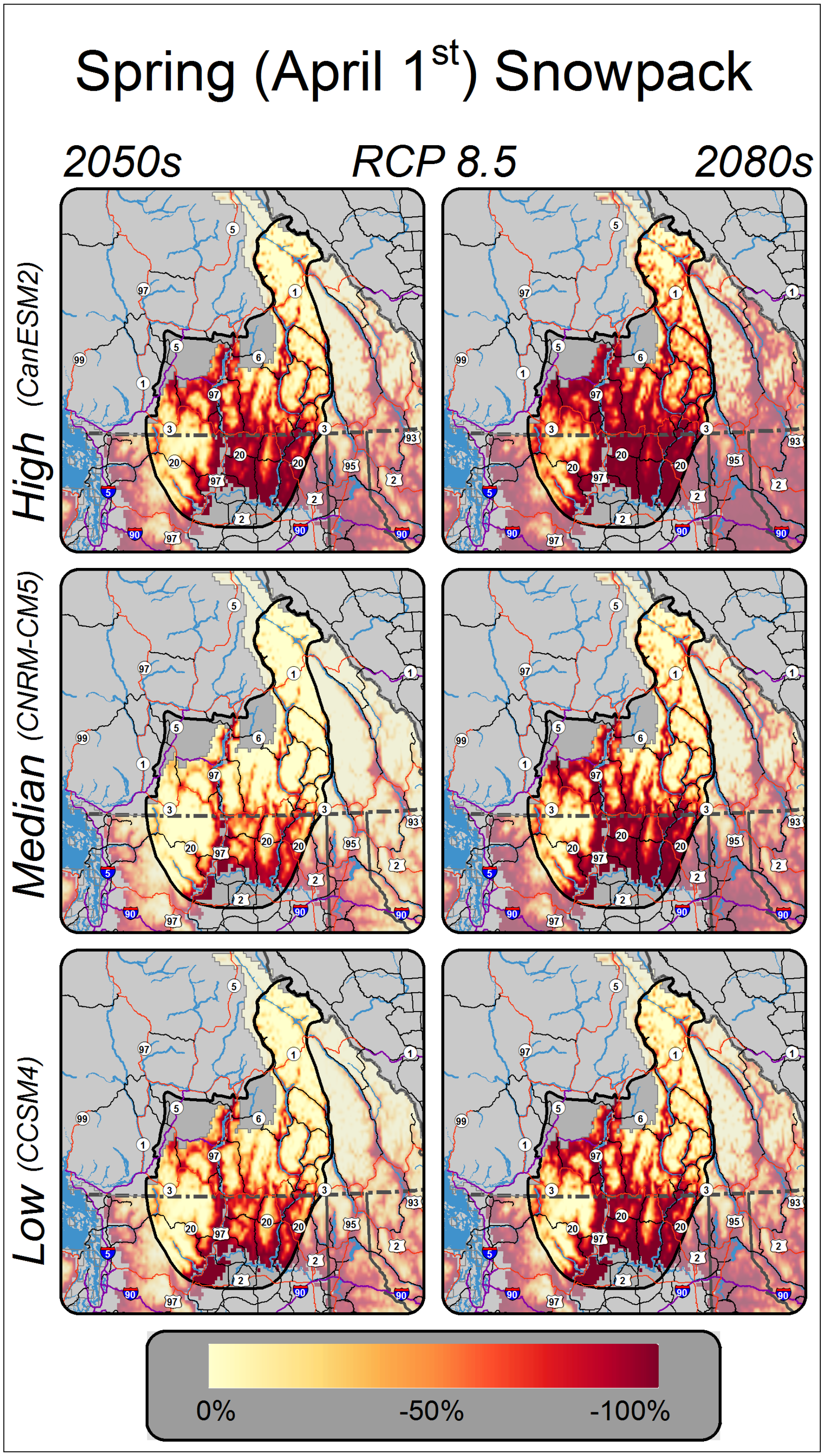
c) **Water Deficit, July-September.** This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

d) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xviii] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

[xvii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.
[xviii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology* 33: 121-131.

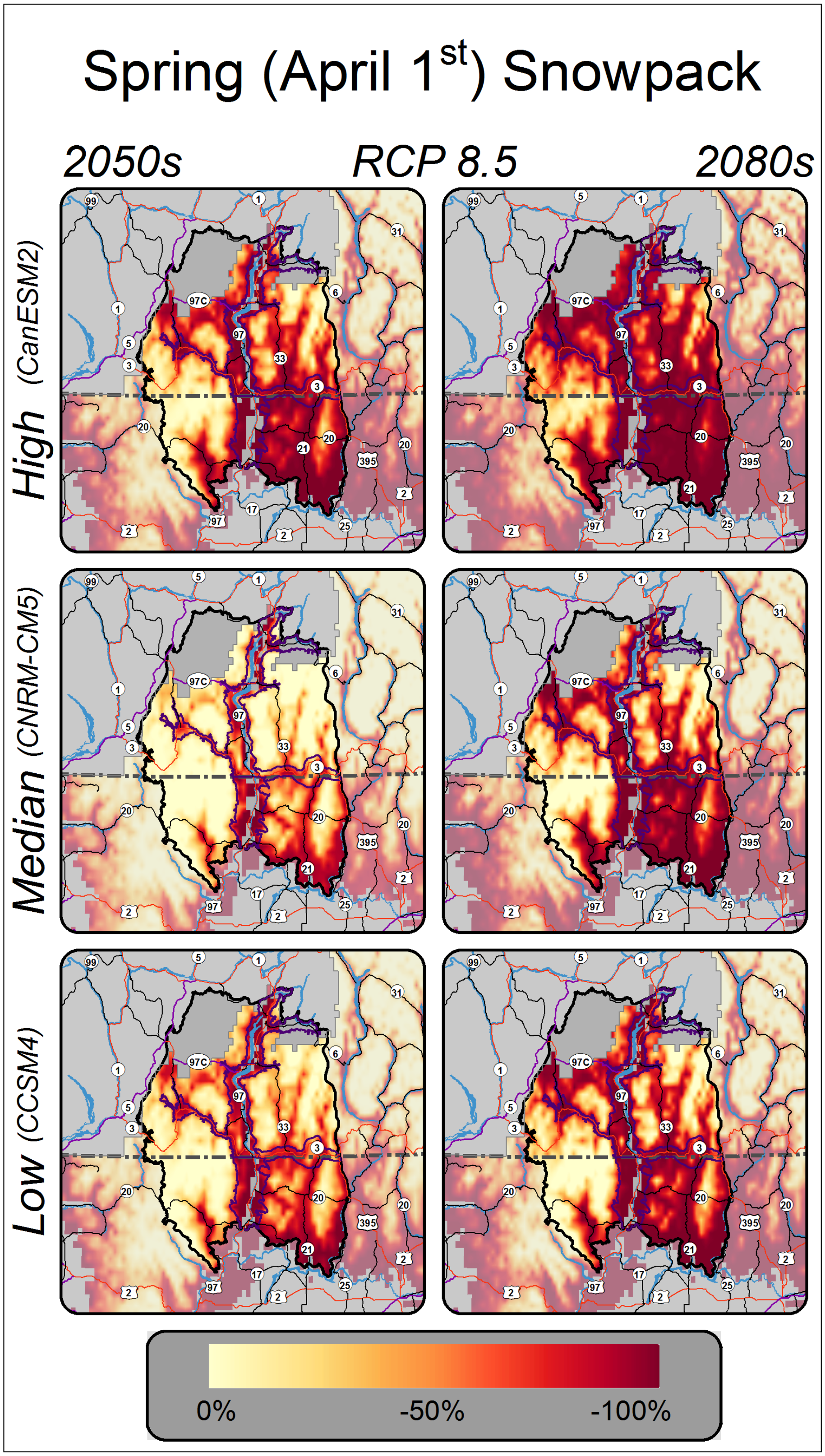
Appendix A.6a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



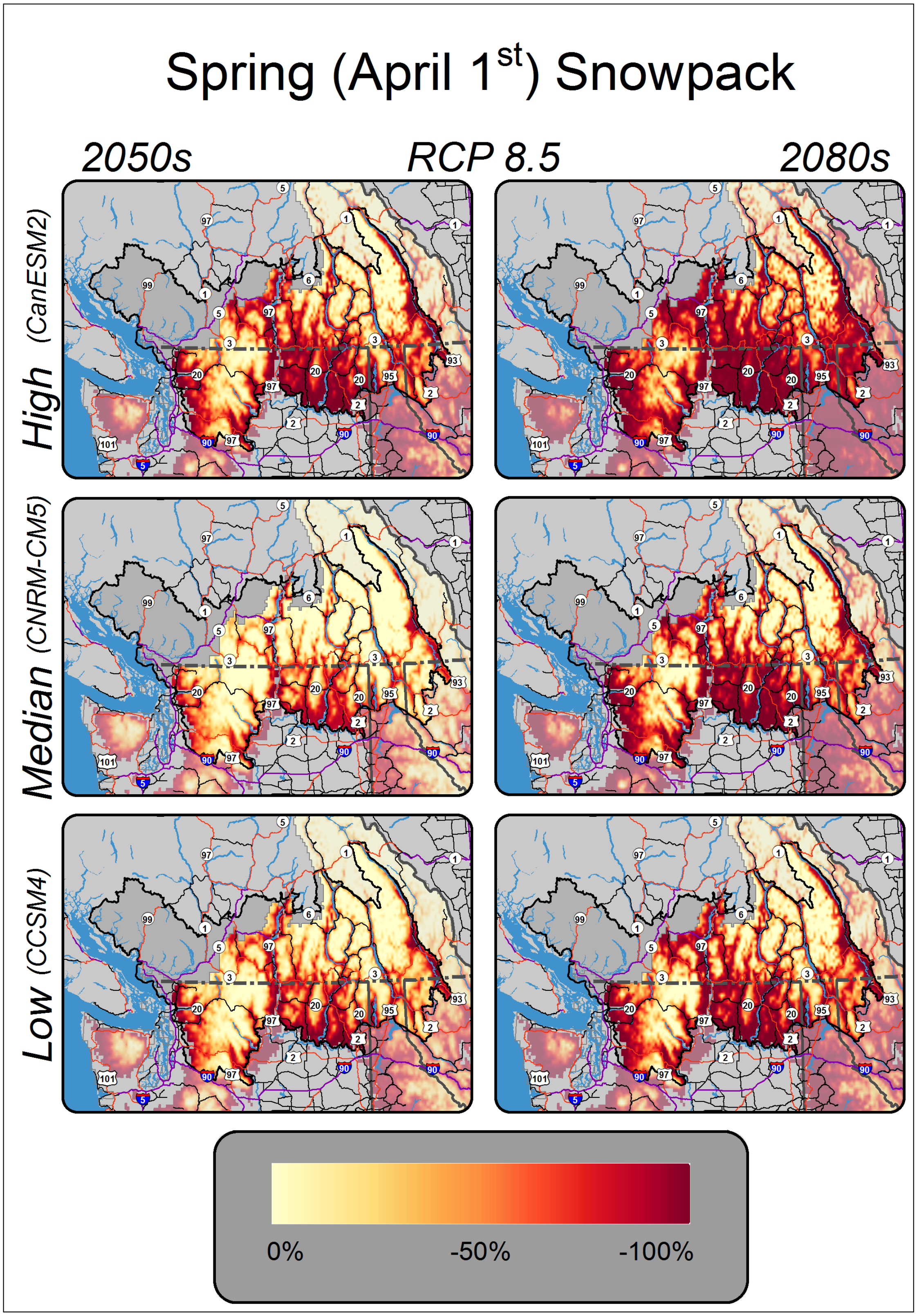
Appendix A.6a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



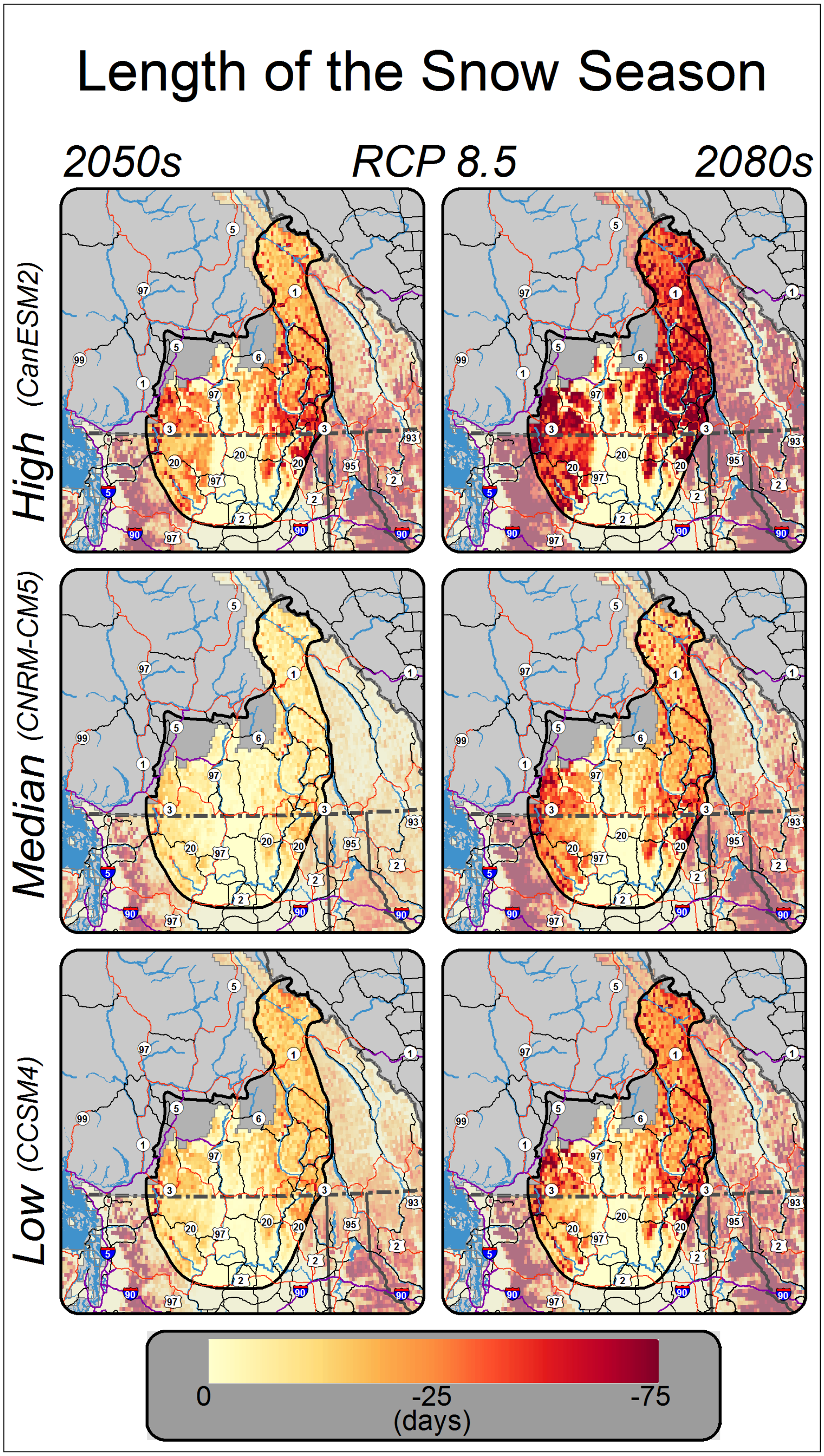
Appendix A.6a. April 1st Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



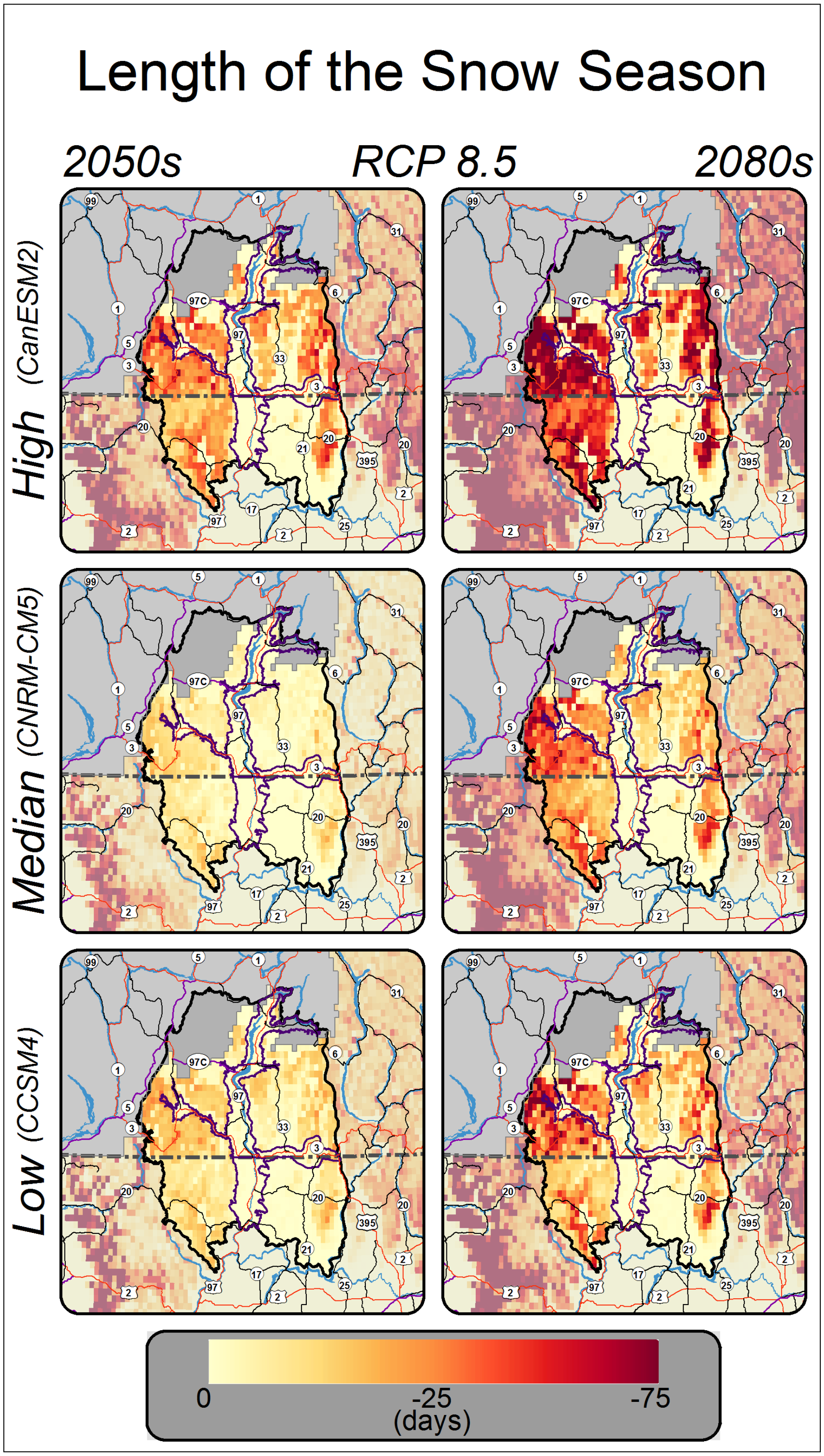
Appendix A.6b. Length of the Snow Season

i) Extent: Okanagan Nation Territory



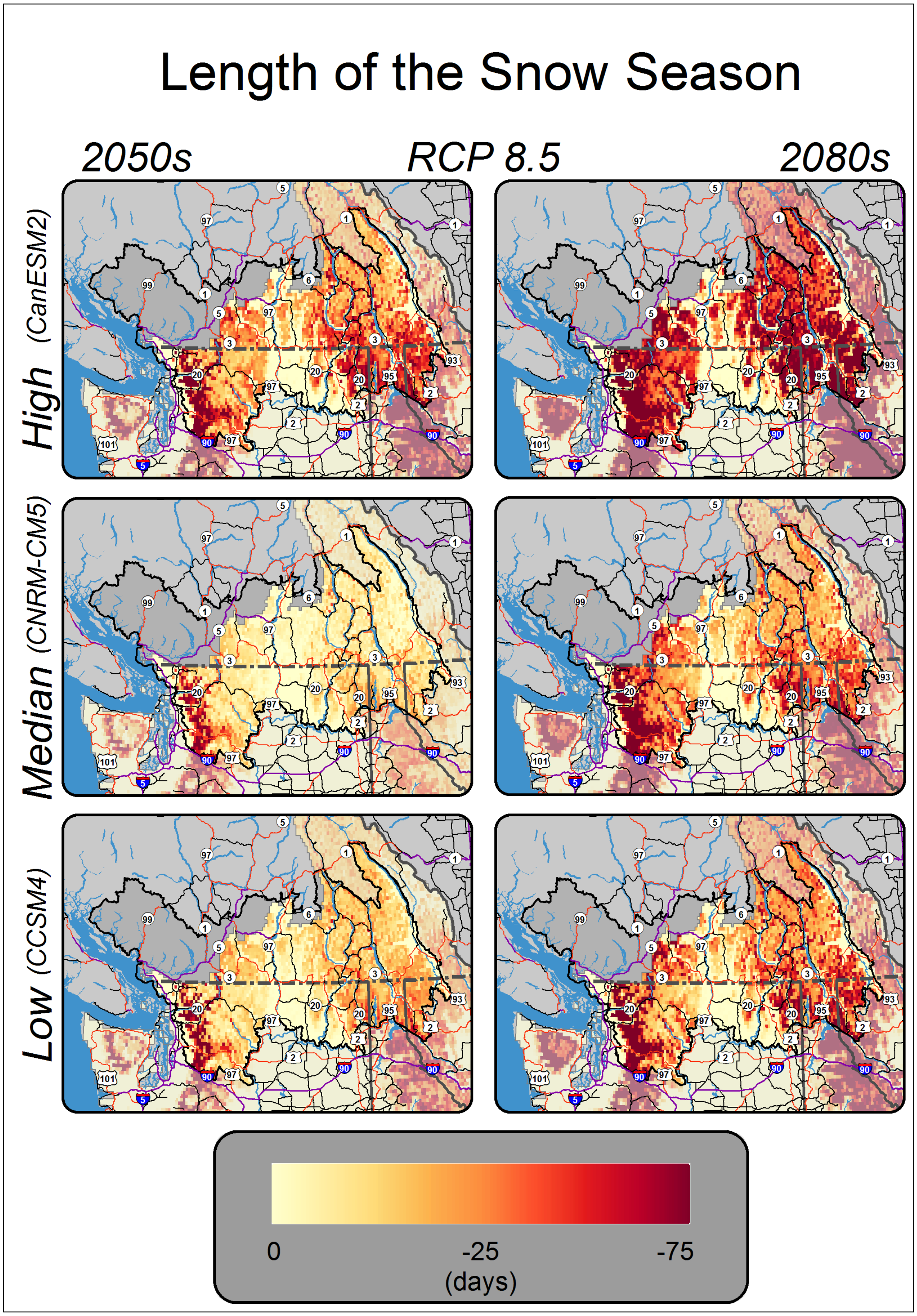
Appendix A.6b. Length of the Snow Season

ii) Extent: Okanagan-Kettle Region



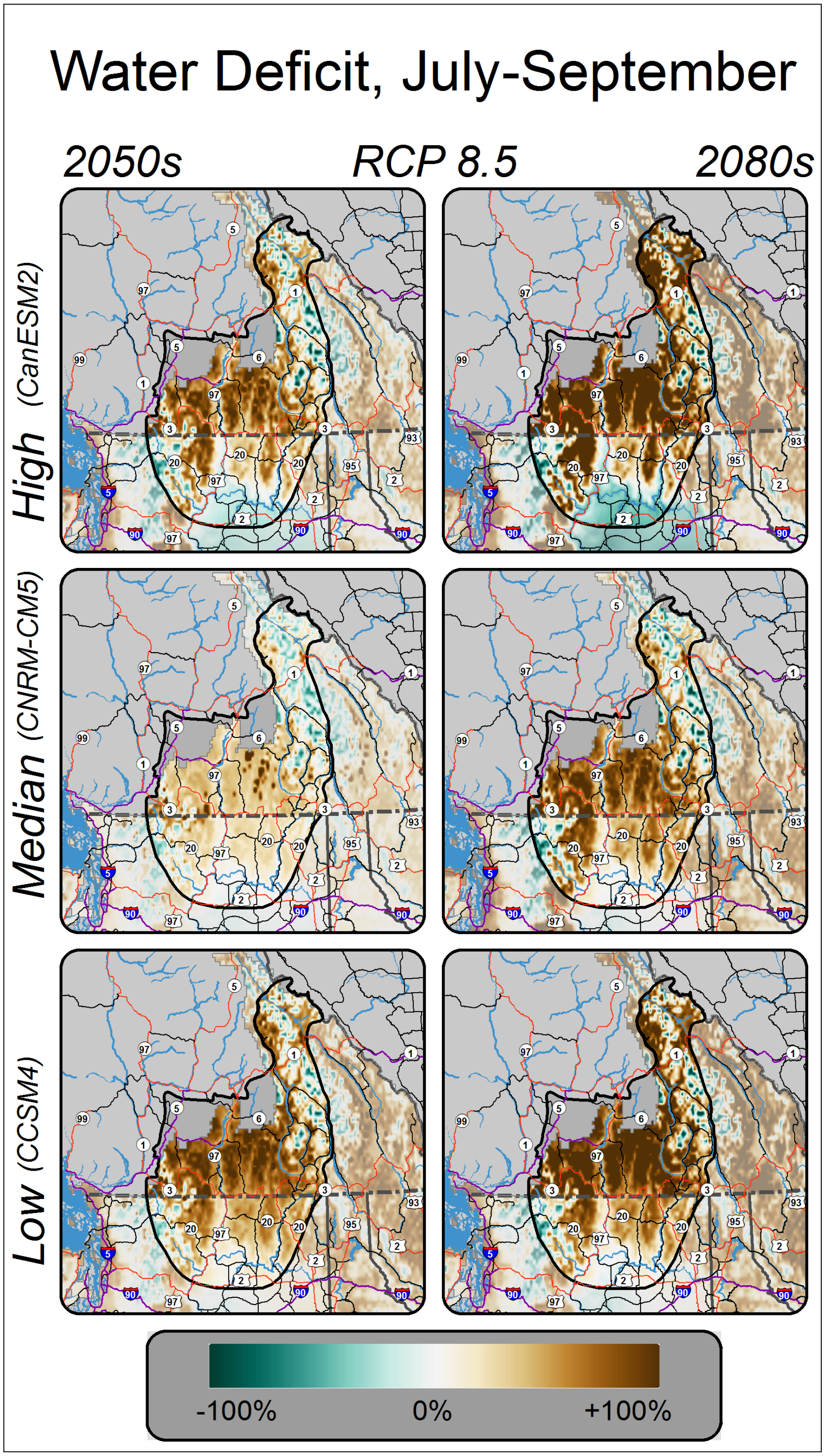
Appendix A.6b. Length of Snow Season

iii) Extent: Washington-British Columbia Transboundary Region



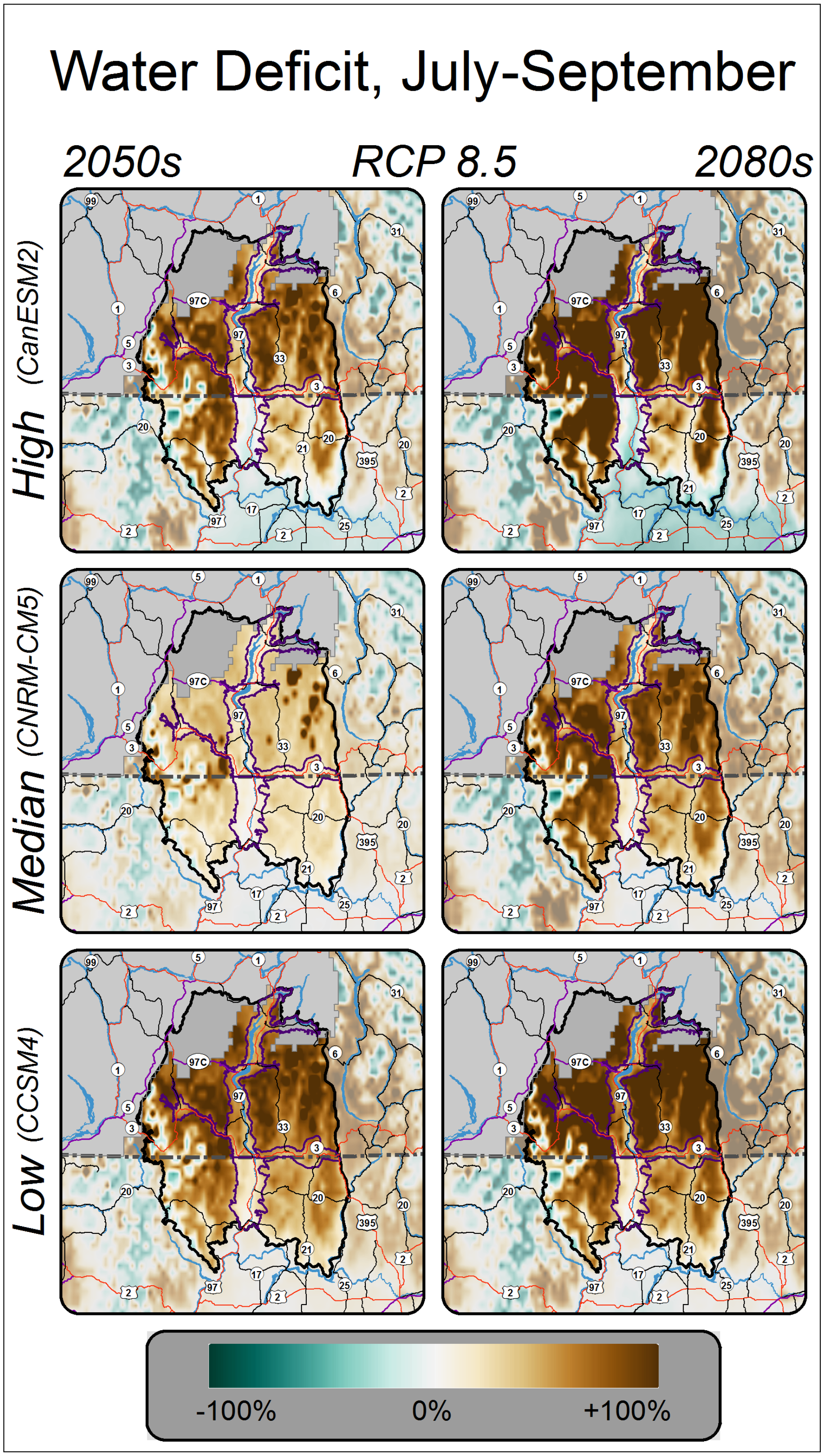
Appendix A.6c. Water Deficit, July-September

i) Extent: Okanagan Nation Territory



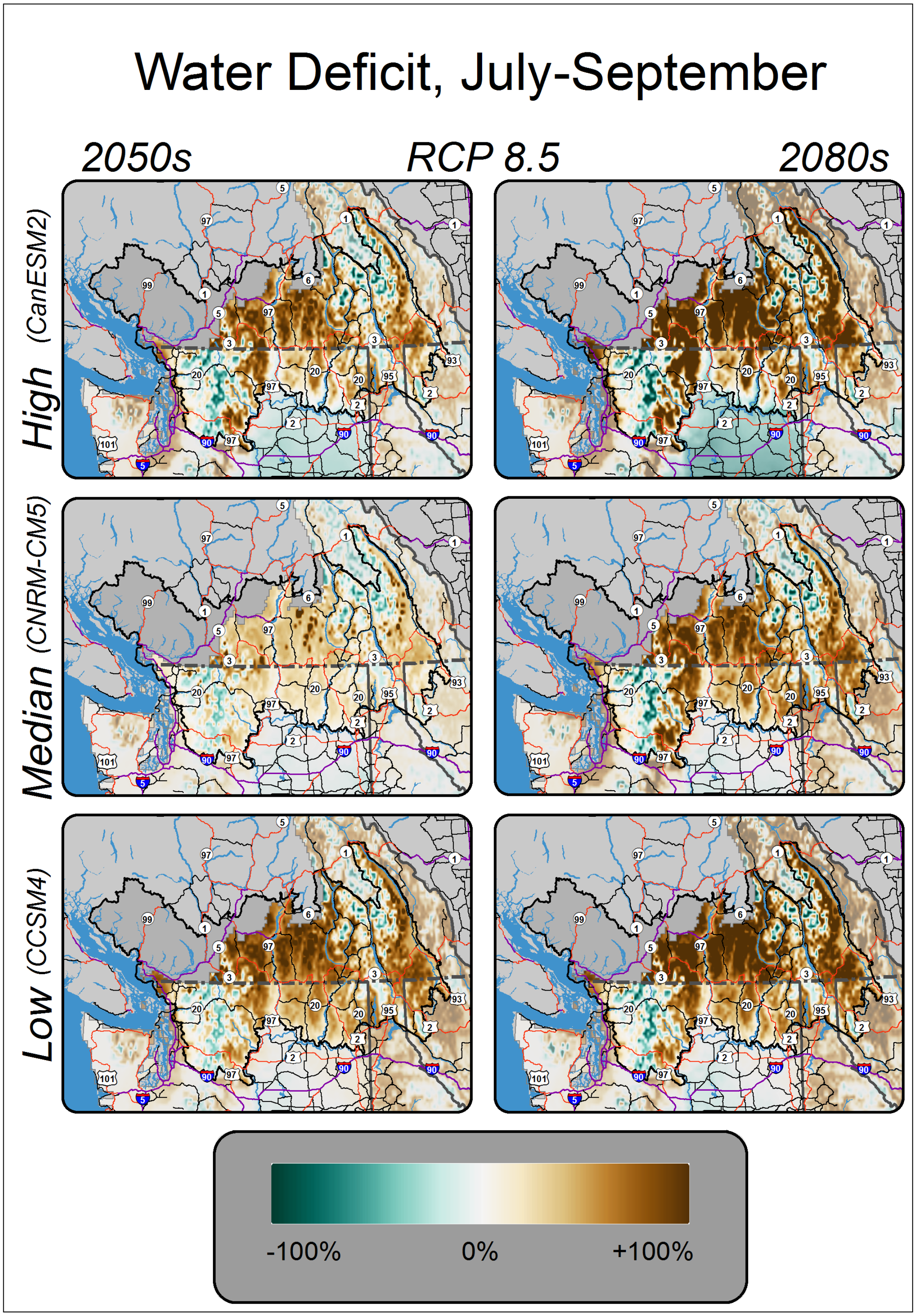
Appendix A.6c. Water Deficit, July-September

ii) Extent: Okanagan-Kettle Region



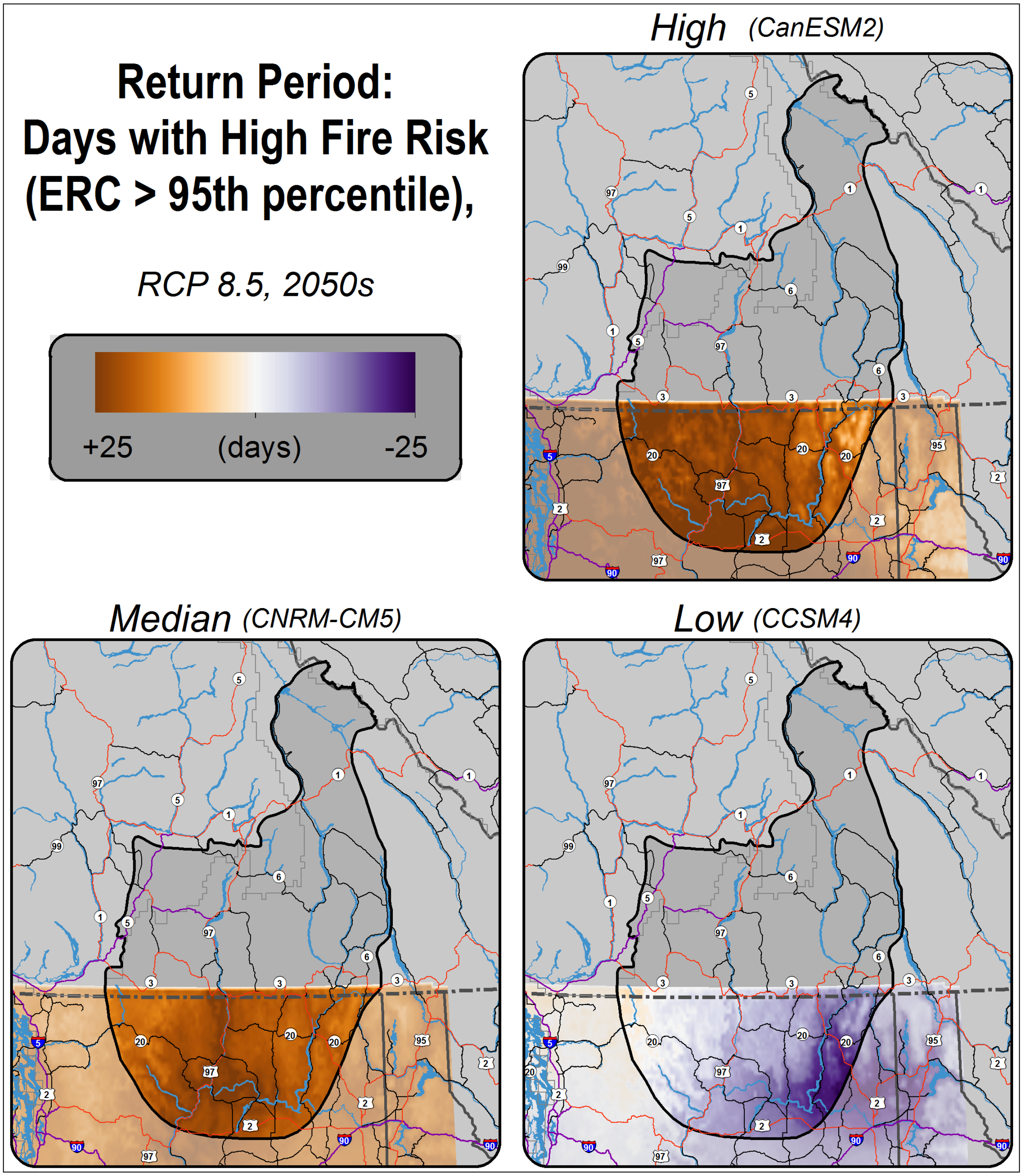
Appendix A.6c. Water Deficit, July-September

iii) Extent: Washington-British Columbia Transboundary Region



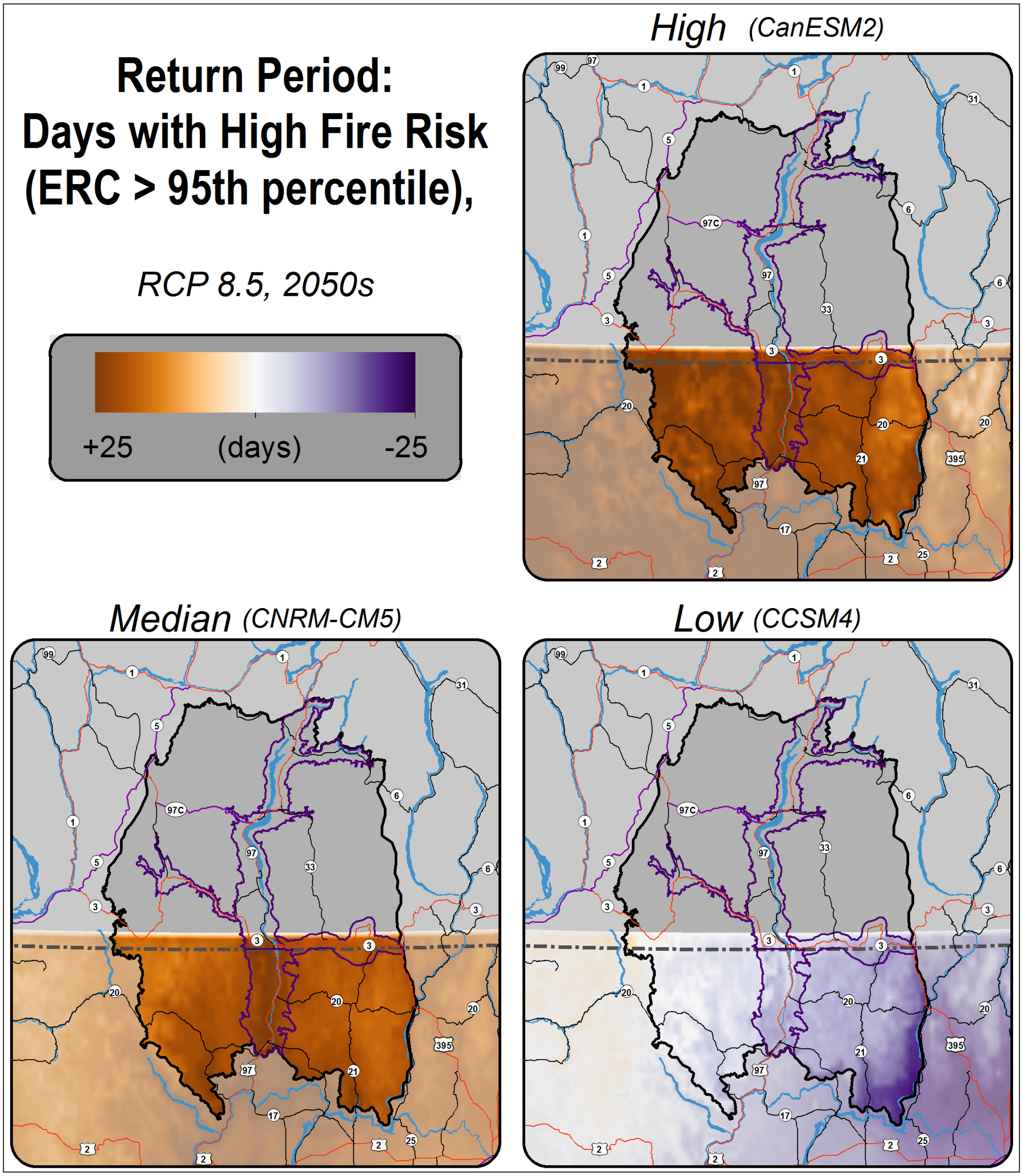
Appendix A.6d. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



Appendix A.6d. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



Appendix A.6d. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region